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NOTES ON THE INTEGRATING SPHERE AND ARC LAMP PHOTOMETRY.*

BY N. K. CHANEY AND E. L. CLARK.

Synopsis: After a brief historical introduction, the paper undertakes an exhaustive analysis of the characteristics of the integrating sphere, with special reference to the asymmetry in integrating properties arising from the necessary introduction of screens and opaque bodies. A mathematical expression is developed for the error of integration, which contains factors depending upon the reflecting power of the sphere walls; upon the relative size and position of the screen with respect to the light source, and to the photometric window; and upon the distribution of the light flux from the sources under comparison. Experimental data verifying the general theoretical conclusions are given. An earlier paper on this subject is criticized, particularly the statements regarding the use of translucent screens, and the measurement of extended light sources. The conclusion reached is that translucent screens are not desirable and that extended light sources of sizes now common among modern arc lamps do not give erroneous values when measured in a properly designed sphere. A summary of the conditions which should be maintained in a sphere to secure accuracy is given. The method used in the photometrical laboratory of a large manufacturing company for comparing various carbons used in a variety of lamps is described. A rational method of proportioning the measurements made upon a single trim to the number of trims measured is given.

The integrating sphere has received relatively less attention at the hands of American investigators than that accorded it abroad. Among the more important contributions to our knowledge of the sphere in this country is the paper read before this society by Sharp and Millar in 1908.[1] The latter contains an excellent illustrated description of integrating spheres and their equipment together with an account of the special advantages offered by their use. It is unfortunate, however, that in the limited space at their disposal the authors felt obliged to deal so briefly with the theoretical aspects of the subject, and that they failed to indicate the more exhaustive treatment to be found in the original literature.

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

[1] TRANS. I. E. S., vol. III, p. 502.

The present paper suffers somewhat from the same defect. No pretense is made of giving an adequate resume of the voluminous German articles upon the subject. Owing to the long delays experienced in securing the original papers, the work here reported took its point of departure from the above-mentioned paper of Sharp and Millar. Theoretical developments which differ somewhat in form from the German were followed independently.

A brief historical survey shows that the earliest forerunner of the spherical integrator was the "lumen-meter" of Blondel, in 1895. Three forms are mentioned in which the light source was placed in the center of an opaque sphere, through which light could leave from one or more openings and after a certain number of reflections be thrown upon a screen and photometered. Its application was limited to axially symmetrical light sources.

The Matthews integrating mirrors designed in 1901 suffer from the same limitation, unless the radially asymmetrical light sources can be rapidly rotated.

The fundamental theorem of the modern spherical integrator, was first mathematically developed by an Englishman, Sumpner, in the *Philosophical Magazine* in 1893. He stated that "any bright patch on the inner surface of a diffusely reflecting sphere illuminates each part of the sphere to the same extent". It follows conversely that any area upon the inner surface of such a sphere is illuminated by all of the other bright patches proportionally to their brightness only, and irrespective of their position. In other words any given area is illuminated proportionally to the average illumination of the rest of the sphere. Sumpner, however, overlooked the practical application of his theorem to integration of asymmetrical light sources until after Ulbricht in 1900 had independently derived the same theorem and applied it to the determination of the mean spherical candlepower of light sources by a single measurement.

The Ulbricht integrator, as is well known, consists of a hollow sphere with a white diffusely reflecting coating and having in its wall a small opening or photometric window. The light source is placed in the sphere and a small screen placed between it and the photometric window or test plate, so that the latter receives

no light directly from the source, but only that reflected to it from the walls of the sphere. The average illumination upon the walls is proportional to the total light flux and by Sumpner's theorem[2] the illumination of the test plate area would be exactly proportional to the average illumination of the sphere wall, that is, to the total light flux, except for one fact, *viz.*, the introduction of the opaque screen into the sphere.

It is evident that the variable direct light flux must be screened from the test plate windows, otherwise the test plate will receive an amount of light varying with the position and distribution of the source. It is also evident that the presence of the necessary screen invalidates the rigorous application of the fundamental theorem of light integration which we have just been considering.

Sumpner's theorem is valid only for an empty sphere. The theorem does not state that all parts of the sphere wall are equally illuminated, for this is contrary to fact with asymmetrical light sources. Therefore if the test plate window is to receive an illumination exactly proportional to the total light flux, it must receive light from the entire sphere wall. This will be prevented by the presence of screens or opaque bodies of any kind.

The effect of a screen is not only to prevent a certain portion of the direct light flux from reaching the sphere wall, but also to screen an opposite part of the sphere wall from the test plate. The resulting situation is readily seen by the screen and sphere diagram, as shown in Fig. 1, A and B.

The effect of the screen is to divide the sphere into three zones or areas as shown in Fig. 1, B. Each of these three zones possesses different physical characteristics. Zone I is not visibly distinct from Zone II. It is the part of the sphere wall concealed by the screen when observation is made through the test plate window at C. The direct light flux falling upon Zone I

[2] Mathematical proof of Sumpner's theorem.—Assuming the validity of Lambert's cosine law the illumination, E, which any infinitesimal area, ΔA, will receive from any other similar area of brightness, e, is expressed as follows:

$$E = \frac{e\Delta A}{4\pi r^2}.$$

With a given sphere radius this expression contains no variable except the brightness of the patch e, and hence is independent of its distance or position.

cannot directly illuminate the test plate at C, but must suffer an additional reflection before reaching the test plate.

Zone III is visible when the sphere is in operation. It is the projection on the sphere wall of the shadow of the screen. It measures the solid angle of the direct flux intercepted by the screen. The flux falling upon the screen (as measured by Zone

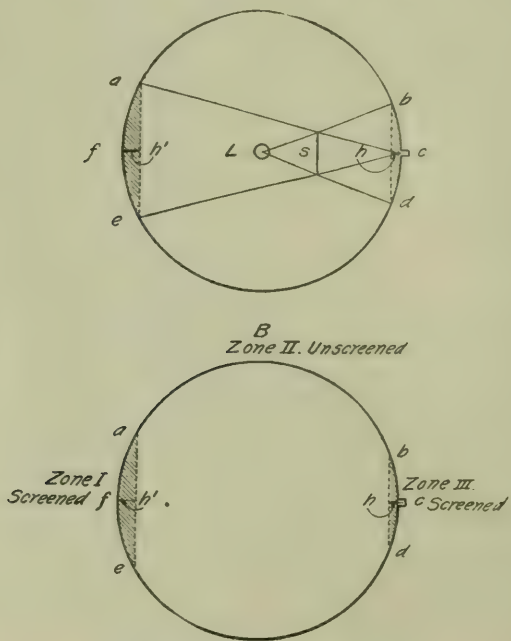

Fig. 1.—Screen and sphere diagram.

III) must be first reflected to the central zone before it can contribute to the illumination at the test plate. Thus Zones I and III comprising the "screened areas" both differ from the "unscreened" central area or Zone II, in a like manner. That is, the light flux directed towards either of the "screened areas" must suffer one additional reflection, and consequent loss by absorption, in comparison with the light flux falling upon the "unscreened" central zone. The latter alone possesses the characteristics required for perfect integration. All of the flux upon Zone II contributes in direct proportion to the illumination at the test plate C.

The spherical integrator is not therefore a theoretically perfect instrument. It cannot be so designed as to integrate perfectly every conceivable type of light flux regardless of the distribution of the latter in the sphere. It may be so designed, however, as to reduce the error to any desired limits. With this fact clearly in mind it evidently becomes necessary to inquire very exactly into the limitations and characteristics of the spherical integrator.

The mathematical treatment here employed, although developed independently, is in some respects substantially similar to the earlier work of Ulbricht but is less complicated in form and leads to simpler generalizations. The problem is treated in part graphically and in part by a few general considerations from which may be deduced a characteristic mathematical expression for the integrating properties of the sphere.

As shown by Sumpner the walls of any enclosure possess an illumination much greater than that corresponding to the intensity of the original light flux. When light falls upon a reflecting surface, part of it is absorbed and part is reflected, the relative amounts depending upon the absorption coefficient a and the reflection coefficient ρ whose sum is unity.

The total illumination on the sphere wall I, is thus made up of two parts:

(1) The direct illumination from the light source I_d, (2) plus an infinite number of reflections from the walls or the reflected illumination I_r

$$I = I_d + I_r \quad \ldots\ldots \quad (1)$$

or

$$I = I_d + \rho I_d + \rho^2 I_d + \ldots + \rho^{(n-1)} I_d = \frac{I_d\,(1-\rho^n)}{1-\rho}\,.$$

Hence

$$I = \frac{I_d}{1-\rho} = \frac{I_d}{a} \quad \ldots\ldots \quad (2)$$

or

$$I = I_d + \rho I \quad \ldots\ldots \quad (3)$$

and

$$I = aI + \rho I \quad \ldots\ldots \quad (4)$$

The ratio of the direct illumination to the total is thus given by

the absorption coefficient, and the ratio of the reflected illumination to the total is given by the reflection coefficient.

Now the direct illumination of average value I_d, varies in intensity at different parts of the sphere according to the distance and degree of asymmetry of the light source. Its average amount is 20 per cent. of the total illumination I, for the usual value of the absorption coefficient, a is about 0.2.

The reflected illumination ρI, usually amounting to 80 per cent. the average total illumination, is equal in all parts of an empty sphere.

Therefore the direct illumination from the light source, I_d, is screened from the test plate in order to measure the reflected illumination, ρI.

The presence of the screen, however, destroys the uniformity of the illumination ρI so that its true or average value is no longer identical with the apparent value at the test plate.

The source of error in integration thus depends upon the manner and extent to which the reflected illumination as actually read at the test plate, differs from the theoretical value of the reflected illumination ρI for an empty sphere. Any constant difference between the observed and the theoretical values of ρI will be corrected by the substitution method of determining the "sphere constant" with a standard lamp, and therefore may be ignored. But variable differences, dependent in any manner upon the character or position of the light source can not be so corrected and constitute a source of error the magnitude and characteristics of which must be known.

It the reflected light ρI be separated into two components it will be found that one component depends upon the light flux in a constant manner, and the other in a variable manner.

From equation (3) multiplying through by ρ gives an expression for the two components of ρI

$$\rho I = \rho I_d + \rho^2 I \qquad (5)$$

That is the reflected illumination consists of the first reflection, ρI_d, of the direct illumination I_d, plus the sum of the succeeding multiple reflections $\rho^2 I$.

Since all reflections after the first are assumed to be completely diffused by the character of the surface of the sphere, the component $\rho^2 I$ is independent of the character or degree of asymmetry

of the original surface illumination by direct light. It will, however, suffer a slight constant reduction, due to the absorption of the diffusely reflected light by the surface of the screen. The component $\rho^2 I$ amounting to 80 per cent. of ρI (if $\rho = 0.8$) is therefore subject to perfect correction in the "sphere constant.[3]

The case is different, however, in the first component of ρI which consists of the first reflection ρI_d of the direct illumination I_d.

The position upon the surface of the sphere on which the illumination I_d exists, determines whether any part of its first reflection ρI_d will reach the test plate or whether the illumination at the test plate will consist only of the subsequent reflections $K\rho^2 I$ .... (6)

A glance at Fig. 1 shows that if the direct light flux falls entirely upon the central area (Zone II) the first reflection ρI_d will be represented at the test plate C.

That is, the observed illumination at the test plate is

$$I' = \rho I_d + K\rho^2 I \quad \ldots\ldots (7)$$

But if the direct light flux falls entirely upon the screened areas (Zones I and III)[4] the component due to the first reflection ρI_d will be intercepted by the screen, and the observed illumination at the test plate is

$$I' = K\rho^2 I \quad \ldots\ldots (8)$$

The maximum difference in the illumination I' due to asymmetry of light flux is therefore equal to ρI_d, or is the fraction $\frac{\rho I_d}{\rho I} = \alpha$, of the theoretical reflected illumination ρI of an empty sphere .... (9)

If δ = fraction of total direct light flux falling upon the screened areas, then the actual illumination at the test plate from the component ρI_d is $(1 - \delta)\rho I_d$. Hence the fraction of ρI read at the test plate is

$$\frac{I'}{\rho I} = \frac{(1 - \delta)\rho I_d + K\rho^2 I}{\rho I} = (1 - \delta)\alpha + K\rho \quad \ldots\ldots (10)$$

[3] If K = fraction of $\rho^2 I$ not absorbed, the illumination at the test plate is $K\rho^2 I$ for the second component.................................. (6)

K is almost unity if the screens are small compared with the surface of the sphere.

[4] The light flux falling upon the screen is measured by Zone III. Hence Zones I and III may be treated in the same manner.

The actual error of integration, E, not compensated by the standard lamp method of determining the "sphere constant" is equal to the difference between the fraction of ρI read at the test plate with the unknown lamp, and that read with the standard lamp.

If δ' = fraction of direct light flux falling upon screened areas with standard lamp and

δ = fraction of direct light falling upon screened areas with unknown lamp, then

$$E = [(1-\delta)\alpha + K\rho] - [(1-\delta')\alpha + K\rho] = \alpha(\delta'-\delta) \quad (11)$$

As δ' and δ are coefficients representing fractions of light flux they may be expressed in terms of illumination and area.

Let

$$\sigma = \frac{\text{Sum of screen areas}}{\text{Total area}}, \text{ and}$$

$$\theta = \frac{\text{Direct av. illumination on screened area}}{\text{Direct av. illumination on total area}}$$

then

$$\delta' = \sigma\theta' \text{ for standard lamp}$$

and

$$\delta = \sigma\theta \text{ for unknown lamp.}$$

Hence

$$E = \alpha\sigma(\theta' - \theta) \quad (12)$$

Equations (11) and (12) are the most general forms of the mathematical expression for the integrating error of the sphere. Space does not permit a detailed account of all of the interesting characteristics of the spherical integrator as shown by this expression.

It is obvious, however, that the error of integration increases with the magnitude of the absorption coefficient, with the size of the screened areas relatively to the total area, and with the difference in the relative illumination of the screened areas by the standard lamp and the unknown lamp, and that the error is zero only when the average distribution of light flux upon the screened areas is the same for standard and unknown lamps.

Since δ, or θ (that is, the ratio of flux or illumination respectively) depends upon the distance of the sources from the screened areas, the relative positions of the standard lamp and unknown lamp as well as their distribution curves must be considered before assuming that the error is necessarily zero when the standard and unknown lamps have the same distribution, or is greater than zero if two sources have unlike distribution.

Our general equation shows the error of Presser's suggestion that a grey wall with an absorption coefficient of 0.5 would give better results than a lower value of 0.2. The argument advanced was that the higher absorption coefficient suffered less change by reason of the collection of dust and dirt upon the sphere walls. While this is true, the remedy is not to allow the walls to become dirty, rather than to attempt to match the dirt by the initial color of the sphere. The change suggested more than doubles the integrating error.

Ulbricht also states that a large absorption coefficient causes greater deviation from the cosine law, and lessens the range of the sphere for lights of low intensity.

Further, the general equation shows that the error of integration may be decreased by decreasing the size of the screened areas or Zones I and III shown in Fig. 1. An inspection of the diagram shows that if a point source be situated in the center of the sphere the screened area $(a\ f\ e)$ or Zone I will be a maximum when the screen, S, is nearest the test plate C, while the screened area $(b\ c\ d)$ will be a maximum when the screen is nearest to the light source L.

At some intermediate position, the sum of these two screened areas will therefore be a minimum.

This minimum position may be graphically determined by drawing diagrams of the intermediate positions upon plotting paper, and noting at which position of the screen the sum of the two lines $f\ h'$ and $h\ c$ are a minimum. Ulbricht has developed general mathematical expressions for the sum of these two areas and the conditions for which they are a minimum. He finds that the horizontal distance of the screen from the center of the sphere should be $0.39 \times R$, if $R =$ radius of sphere, and

the light source is at the center.[5] If the light source be above the center making an angle of 35° with the test plate and the horizontal, the value is smaller, about $0.29 \times R$, the screen being elevated proportionally. (This design is advocated by several German writers, especially for arc lamps with a large lower hemispherical light flux). In general, however, a value of $0.4 \times R$ may be accepted as the best distance between lamp and screen.

Having placed the screen in the position for minimum area of Zones I and III, this area may be further decreased only by increasing the size of the sphere, since the size of the screen is determined by the area of the largest light sources to be measured, or by the cross section of the largest diffusing globes employed. The largest permissible ratio between the screen and sphere diameters must be arbitrarily determined by the limits of error within which it is desired to work.

Ulbricht estimates that the cross section of the sphere must be at least twenty times the cross section of the screen, or with circular screens the diameter of the sphere must be over 4.5 times the diameter of the screen. In this case the sum of the screened areas is 20 per cent of the sphere area for a point source in the center of the sphere. Therefore, with a symmetrical light source $\delta = 0.2$ and the reflected illumination at the test plate is diminished by the fraction

$$\frac{0.2\rho I_d}{\rho I} = 0.2a = 4 \text{ per cent. if } a = 0.2 \ldots\ldots\ldots \quad (10)$$

The error, however, by the general equation (10) is

$$E = a\sigma(\theta' - \theta) = 4 \text{ per cent. } (\theta' - \theta)$$

in which $(\theta' - \theta)$ may have values of from 0 to 5 respectively. $\theta \cdot \frac{\delta}{\sigma} \leq \frac{1}{0.2}$. If the light flux from the standard lamp is

[5] Some latitude is possible since small changes in the screen position are partly compensating in their effect upon the magnitude of the screened areas.

Chillas has calculated that with a screen diameter one fifth of the sphere diameter the position for minimum screened areas is at the distance 0.372R from the sphere center, in which case the magnitude of the screened areas is 15.0 per cent. of the sphere area. The ratio of the area of Zone I to the area of Zone III is 3 to 2 for minimum areas.

For screened areas of equal size the distance of the screen from the center is about 0.315R ond the sum of the screened areas is 15.6 per cent. of the sphere area, an increase in the screened areas but 0.6 per cent. over their minimum value.

approximately symmetrical, $\theta' = 1$ and therefore θ, the ratio of the average direct illumination upon the screened areas to the average direct illumination on the sphere wall as a whole, must be not less than 0.75 or greater than 1.25 if the error of integration is to be not more than 1 per cent. Since θ may quite easily vary from 0.5 to 2.0 giving an error of 2 to 4 per cent. it would seem that the ratio between screen and sphere diameters selected by Ulbricht is much too large even as a maximum, if the error is to be kept below 1 per cent. for light sources of very different types of distribution. The 80-inch sphere requires a screen of but one sixth the diameter of the sphere and the screened areas are but 12 per cent. of the total area. This cuts down the above limits of error nearly one half.

In arc lamp photometry a further source of complication is that the standard lamp must be read while the unlighted arc lamp is in the sphere in order to correct for the absorption of light by the lamp parts and the screening effect which it has as an opaque body.[6]

A second screen (s' in Fig. 2) is therefore required which

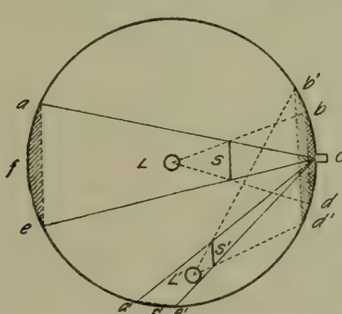

Fig. 2.—Two-screen diagram.

screens another part of the sphere wall (a' e' f') from the test plate. This screen s' may be quite small as the standard lamp filaments need not require a large screen. Fig. 2 shows, however, that if the lamp be moved from the position L′ to L the relative amount of total light flux falling upon the two screened

[6] Any opaque body acts in two ways to diminish the illumination at the test plate. It absorbs an amount of light proportional to its surface area and the absorption coefficient of its surface, and it screens a part of the sphere wall from the test plate, depending upon its shape and relative position in the sphere.

areas $(a\ c\ f)$ and $(a'\ e'\ f')$ will alter with the change in the relative distances from the areas. The position and size of the screen, s', must be so chosen, therefore, that the relative screened areas $(b\ d\ c)$ *and* $(b'\ d'\ c)$ at the test plate will be in compensating ratio. As Ulbricht has shown, if the light sources have a pronounced asymmetry the relative flux in the different directions must be determined from the distribution curves of the lamps and corrected for.

This is obviously unsatisfactory, and the rational correction is therefore to construct spheres of sufficient size to make the influence of the screened areas small and the effect of their relative proportions negligible. In other words if σ, in the general equation

$$E = a\sigma(\theta' - \theta)$$

is not greater than 1/10, the screen errors may be neglected for light sources of ordinary distribution.

Before considering the case for extremely asymmetrical sources, it will be convenient to derive a special form of the general equation applicable when the standard lamp has a distribution sufficiently symmetrical to give the same average direct illumination upon the screened areas as upon the unscreened area. In this case

$$\delta' = \sigma$$

and

$$E = a(\delta' - \delta) = a(\sigma - \delta) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

Since both a and σ are known or may be determined for any given sphere, the error becomes a constant multiplied by but one variable factor depending upon the distribution of the light flux of the unknown lamp.

For example with the 80-inch (2.03 m.) integrating sphere in this laboratory

$$a = 0.2 \text{ approx.}$$

$$\sigma = 0.1 \text{ approx.}$$

Hence

$$\text{Per cent. } E = 0.2 \times (0.1 - \delta) \times 100.$$

δ may have any value from zero to unity.

If $\delta = 0.0$, then $E = 2$ per cent.
If $\delta = 0.1$, then $E = 0$ per cent.
If $\delta = 0.2$, then $E = -2$ per cent.
If $\delta = 1.0$, then $E = -18$ per cent.

While the maximum possible error is very large it should be noted that the conditions for its occurrence are very unlikely to happen except by design.

The expression $E = \alpha(\sigma - \delta)$ has two maxima $(+\alpha)$ and $(-\alpha)$. In practise, however, σ is never greater than 0.25, hence the maximum of $(+\alpha)$ has no practical significance. The condition that E, approach $(-\alpha)$ is that σ be very small and δ be unity; since $\delta = \sigma\theta$, however, δ usually decreases with σ instead of becoming a maximum. In order for δ to be unity when σ is small all of the light flux must be concentrated upon certain very small portions of the sphere area. In the numerical values quoted for the 80-inch (2.03 m.) sphere $\sigma = 0.1$. Therefore if the total direct light flux should be so asymmetrical as to illuminate but one tenth of the area of the sphere and if the direction of the rays were left to chance, the probabilities are 10 to 1 that none instead of all of the direct light would fall upon the 10 per cent. of screened areas, that is δ would be 0 instead of unity, giving an error of +2 per cent. instead of —18 per cent.

Furthermore it so happens that the screened areas are divided

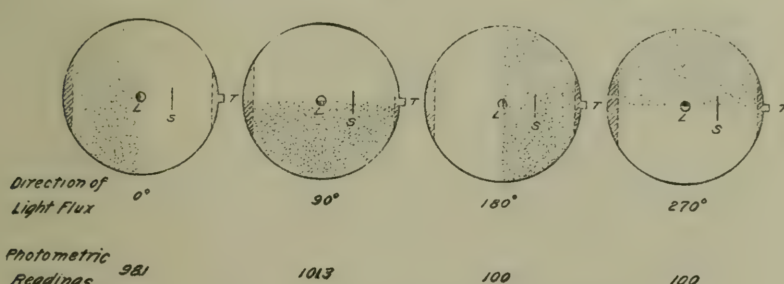

Fig. 3.—Diagram for hemispherical distribution.

and occupy opposite sides of the sphere which renders them still less likely to receive the entire flux of extremely asymmetrical sources. This is well illustrated by Ulbricht's classic experiment of rotating a lamp in the sphere one side of which was covered with black paint. Thus a light source having an approximately hemispherical distribution was obtained. In a 20 inch (50.8 cm.) sphere, values were obtained as shown in Fig. 3.

The light flux is directed toward the screen and then is given

successive 90° turns. The readings indicate a very high degree of integrating capacity for so small a sphere.

If the same experiment be performed in a properly constructed 80-inch sphere no appreciable difference in the various directions of a hemispherical light source can be detected. An examination of the diagrams will show, however, that the success of the experiment depends upon the relative position of the two screened areas upon opposite sides of the sphere. Assuming that the two screened areas are approximately equal then for each position half of the screened areas are in the shadow of the lamp, and half are illuminated. Therefore, θ, the ratio of direct illumination upon screened areas to the direct illumination upon the sphere as a whole is always equal to 1 and the error of integration is zero $[E = a\sigma(1 - \theta)]$ for all positions of the hemispherically asymmetrical source. The same holds true whether the lamp be rotated upon the horizontal or perpendicular axis. This compensation by position, however, holds only for hemispherically asymmetrical light sources.

If the distribution curve of the lamp has two horizontal maxima such as is caused by heavy side arms in some types of arc lamp, then *both* screened areas might receive the maximum flux in one position of the lamp and *both* would receive the minimum for a rotation of 90°. To map out the real characteristics of the screened and unscreened zones, a much more asymmetrical light source is required which will directly illuminate a fraction of the sphere wall smaller than either of the two screened areas.

An examination was made in this manner of the 80-inch (2.03 m.) metal sphere and an 80-inch wooden, box integrator having an inner surface in the form of an 18-sided polyhedron.

A large tungsten lamp of about 160 mean spherical candlepower was entirely covered with black paper except for one opening of about 2 inches (5.08 cm.). When this was directed toward either of the two screened areas no direct light fell upon the unscreened area. Three positions on the central area were also chosen, so that no direct light fell upon either of the screened areas. The photometric readings are placed in ratio with the 90° reading = 100.

It is seen that in the case of the sphere very good agreement

is obtained for the three positions (45°, 90° and 135°) upon the central zone, or unscreened area. The same positions for the unscreened area of the box show greater asymmetry due to the deviation from the spherical form but considering the concentration of the light flux the variation of 2.5 per cent. is surprisingly low.

On the other hand the values for the positions, 0° and 180°, on the two screened areas, or Zone III and Zone I respectively, show a large drop of approximately 25 per cent. for both the box and the sphere. These values represent the maximum variations possible in the reflected illumination at the test plate and are of the known order of magnitude of the absorption coefficient α, in agreement with the theoretical deduction. (See Equation 9.)

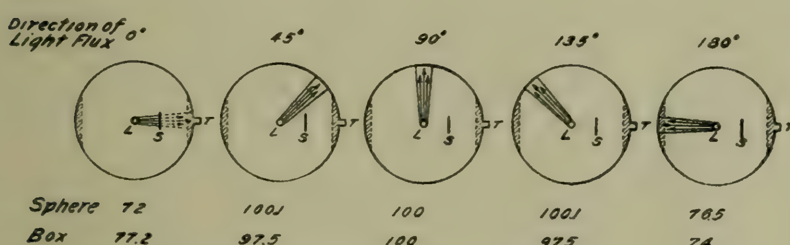

Fig. 4.—Diagram for concentrated flux.

In fact with certain refinements this provides a simple method for determining the absorption coefficients of the sphere wall or of the screen.

It is evident from the foregoing work that extremely asymmetrical light sources may be accurately integrated in a well designed sphere if the precaution is observed to direct the flux entirely upon the central zone. The slight error is easily corrected in two ways. First, if the standard lamp gives the same average illumination upon the screened area ($a\ e\ f$) in Fig 1 as upon the rest of the sphere the error is then $E = \alpha\sigma$ in which both α and σ are known or can be easily determined. Second, a standard lamp which also throws its entire flux upon the central zone may be employed. Then $E = \alpha(\delta' - \delta) = 0$ since both δ' and δ are zero.

It has been shown that the conditions for perfect integration

are, (1) a small absorption coefficient of the sphere walls;[7] (2) the smallest possible percentage of the sphere wall screened from the test plate and from the direct rays of the lamp; and (3), a similar ratio of the light flux upon the screened and unscreened portions of the sphere wall for both the standard lamp and the unknown lamps.

It has been shown from the form of the general equation for integration error

$$E = \alpha\sigma(\theta' - \theta)$$

that the more closely the first two conditions are approached, the greater may be the deviation from the third condition without serious error, while on the other hand if the third condition be exactly fulfilled the first two conditions may be entirely ignored.

Finally it has been shown that with exceedingly asymmetrical light sources the possible error is small if the most intense portion of the flux is always directed away from the screened areas, and upon the central zone of the sphere (*i. e.*, if θ is kept equal to or less than 1).

The remainder of the paper will be devoted first to a discussion of certain points brought forward in the paper of Sharp and Millar already referred to, and second to certain practical considerations arising in arc lamp photometry.

A form of correction for asymmetrical light distribution which is emphasized by Sharp and Millar is the use of a translucent or diffusing screen, instead of an opaque screen between the light source and the test plate. This was originally suggested by Ulbricht in the case of very small spheres in which it was noted that with the rotation of a hemispherically asymmetrical light source, the readings were lowest when the lamp was directed toward the screen. This is the case with the readings for the 20-inch (50.4cm.) sphere in Fig. 3, the drop being about 2 per cent. Sharp and Millar quote much higher values of 11 per

[7] The practise in this laboratory is to use "factory white" and renew the coating every two weeks. This is preferable to using an oil paint and attempting to wash the surface, as a mat diffusing surface is more easily maintained. The relative reflecting power of white porcelain, white blotting paper, and "factory white," for different wave-lengths of light was determined with the spectrophotometer. "Factory white" showed a slightly lower selective absorption in the red end of the spectrum. Otherwise the surfaces were the same.

cent. for an 18-inch (45.7 cm.) sphere and 6 per cent. for a 30-inch (76.2 cm.) sphere. The proposal is to correct for this by selecting a screen just translucent enough to transmit the proper amount of direct light to the test plate and so equalize the readings, for the two positions. This method of compensation is open to the following objections.

(1) The exact adjustment of screens to particular translucencies is neither simple nor convenient in practise.

(2) The compensation is made by the transmission of direct light of varying intensity. Since the sole object of the screen is to prevent such transmission the general integrating capacity of the sphere is impaired and the adjustment is valid only for the particular distribution of light flux for which it is made.

(3) Large errors are introduced by slight variations in the distance of the light source from the screen.

(4) The method is unnecessary. The desired correction can be made by proper screen position. If the reading is low when the light is directed toward the screen, as compared with the reverse position, the relative proportion of the two screened areas is wrong, and may be remedied by moving the screen nearer the test plate.

Much more objectionable than the use of an exactly adjusted translucent screen for a particular type of light distribution has been the indiscriminate use of translucent screens in certain commercial integrating spheres placed upon the market, where there was no pretense of adjustment, and where such use was ill-advised and harmful. An 80-inch integrating sphere of this type, with complete photometric equipment was purchased some time ago from a manufacturer. This sphere was provided with screens made of translucent diffusing paper. Assuming that the screens were properly designed, the sphere was placed in service without special tests. Later a box integrator of the same diameter was built in the laboratory and the arrangement and construction of the screens were copied from the above-mentioned sphere. As the inner surface of the box integrator was 18 sided instead of spherical, a critical investigation was made of its integrating capacity as compared with the sphere. It was found when a series of standardized high power incandescent

lamps were successively suspended in the box, in the position usually occupied by the arc lamp that discrepancies of serious magnitude frequently occurred. The same experiment was repeated in the metal sphere with similar results, the discrepancies amounting to 4 and 5 per cent.

The experiment with the hemispherical light source was then tried with the following results in the box integrator. Three positions were chosen.

TABLE I.

	Toward screen		Away from screen
Direction of light flux	0°	90°	180°
Readings	100	81	74

Since the illumination at the test plate increases 36 per cent. as the light is rotated around toward the screen from the opposite side, it would appear that the compensation for loss of light at the test plate was somewhat excessive.

Opaque screens of blotting paper were then employed and the reading in the three positions differed less than 0.2 per cent. In the sphere a smaller difference of 18 per cent. existed between the two opposite sides, due to the fact that the translucent screen had become somewhat more opaque by reason of age or dust.

But the source of the serious discrepancies with horizontally symmetrical sources was found to be in the fact that the proportion of transmitted light varied with the distance of the lamp from the screen. The translucent screen behaves toward the test plate as a primary light source, and the illumination of the screen necessarily varies with the distance of the lamp.

TABLE II.—TRANSLUCENT SCREENS.

	Distance lamp to screen	Test plate illumination	Per cent. change: Observed	Per cent. change: Calc. inverse square law
Clear globe	9 in. (23 cm.)	20.3	0.0	0.0
	11 in. (28 cm.)	18.9	7.0	8.9
	18 in. (46 cm.)	17.3	14.5	19.0
Diffusing opal globe	9 in.	16.3	0.0	0.0
	11 in.	15.4	5.5	8.5
	18 in.	13.6	16.0	19.0

It is seen from Table II that a displacement of 2 inches gives a change in illumination of about 6 per cent., and a displacement

of 9 inches a change of about 15 per cent. The change is somewhat less than is calculated from the inverse square law.

In the following table the results with opaque screens are given which show no change at all for a displacement of 2 inches (5.08 cm.) and only a slight effect when the distance between lamp and screen is doubled.

TABLE III.—OPAQUE SCREENS.

	Distance lamp to screen	Test plate illumination	Per cent. change
Clear globe	9 in. (23 cm.)	14.9	0.0
	11 in. (28 cm.)	14.9	0.0
	18 in. (46 cm.)	14.7	1.3
Diffusing opal globe	9 in.	12.15	0.0
	11 in.	12.15	0.0
	18 in.	12.10	0.4

Inasmuch as the incandescent lamps were merely suspended in the sphere, variations of over an inch (2.54 cm.) in their position was easily possible, which accounted for the discrepancies observed when the translucent screens were employed. In the case of arc lamps exact centering would be impracticable.

Sharp and Millar make a second indictment of opaque screens, however. They state that—

It has been found that when an opaque screen is used the results are dependent upon the size of the light source tested. So for example, in the 80-inch (2.03 m.) sphere the following differences have been found between results obtained with an opaque screen of the size which it is desirable to use, and those obtained with the smallest opaque screen which could be used in connection with the particular light source investigated.

	Per cent. difference between determinations with large and small opaque screens
100 candlepower carbon filament	2.0
32 candlepower carbon filament	3.0
16 candlepower carbon filament	4.0
8 candlepower carbon filament	5.0
4 candlepower carbon filament (sign lamp)	10.0
2 candlepower carbon filament (sign lamp)	10.0

These data indicate that if an opaque screen were used, an arc lamp with an opal globe would receive an undue advantage in comparison with the same lamp equipped with a clear glass globe.

They further state that—

Errors due both to the opacity of the screen and to variations in the relation between its size and that of the light source may be eliminated by substituting for the opaque screen one of a particular translucency.

The objections which may be raised to the above are two in number: first, that their experiment does not prove what it is intended to prove, and second, that if what they desired to show is true, no conceivable translucency of screens will be of any avail.

In the experiment quoted the ratio between the large and small screen becomes successively greater with each succeeding number of the series. Since the illumination at the test plate depends directly upon the size of the screen, this adequately accounts for the increasing divergence with each successive pair of readings.

In the following table are given readings taken successively with a translucent screen and an opaque screen, first for an incandescent lamp with clear globe, and second, for the same lamp incased in a large diffusing arc lamp globe. The results show that there is the same relative difference, *viz.*, 17 per cent., between the clear globe and the opal globe whether a translucent or an opaque screen be used. Or, looked at in another way, the replacing of the translucent screen with an opaque screen has cut down the illumination at the test plate by almost exactly the same amount, viz., 14.4 per cent., whether the area of the light source was large or small.

TABLE IV.

	Translucent screen	Opaque screen	Per cent. difference
Clear globe	24.78	21.19	14.49
Opal globe	20.56	17.59	14.44
Per cent. difference	17.07	17.00	0.0

Sharp and Millar's conclusions, therefore, upon the value of translucent screens, require revision.

Their original suggestion, however, that the relative areas of the light sources might affect their relative values as determined in the sphere was further investigated. As already shown, the theoretical value of the reflected illumination for an empty sphere is ρI, and the actual value of the reflected illumination read at the test plate with a screen is $[(1 - \delta)\rho I_d + K\rho^2 I]$. The ratio

of the reflected illumination with screen, to that without screen is therefore $[(1-\delta)\alpha + K\rho]$ (10) which for the lack of a better term we will call the 'screen ratio'.

In the above expression α and ρ are the absorption and reflection coefficients of the sphere wall; K is a coefficient representing the fraction of the diffuse reflections $\rho^2 I$ which escapes absorption by the screen, and other foreign bodies, and is therefore nearly unity, and $(1-\delta)$ is the distribution coefficient representing the fraction of the total light flux falling upon the unscreened area or central zone of the sphere. There is nothing in this expression dependent upon the area of the light source. Unless the area of the source changes the distribution of the flux it should be without influence.[8]

The use of diffusing globes upon asymmetrical sources does change the resulting distribution curves giving in general a more symmetrical distribution. This means that the ratio $[(1-\delta)\alpha + K\rho]$ for a clear globe may be either greater or less than the corresponding ratio for the same source with a diffusing globe.

If the clear globe has a relatively large fraction, δ, of the total light flux falling upon the screened areas, a diffusing globe may diminish this and increase the value of the ratio $[(1-\delta)\alpha + K\rho]$. That is, the diffusing globe will have a relative advantage.

If on the other hand the fraction of the light flux, δ, falling upon the screened areas is much below the average, a diffusing globe may increase δ, and diminish the ratio given by the expression $[(1-\delta)\alpha + K\rho]$. That is, the diffusing globe will have a relative disadvantage.

A direct experimental method of measuring the 'screen ratio'

[8] The proof that a large light source will undergo the same screen absorption as a small source of equal candlepower is simple when the distribution is assumed uniform for both cases.

Imagine equal spheres described about the center of both light sources, then since both sources emit the same total flux uniformly distributed, equal portions of the surface on the two spheres are traversed by equal light fluxes. If the radius of the imaginary sphere is so taken that the edges of the circular screen lie on the sphere surface it is clear that the screen marks off a definite portion of the sphere surface and therefore receives the same light flux from either the small or the large light source above assumed. This is the necessary and sufficient condition for equal absorbing effects on both light fluxes.

It is true that the light distribution on the portion of the integrating sphere around the screen shadow is different in the two cases, but this difference has no effect on the illumination at the test plate if the portion of the sphere surface involved has a uniform reflecting surface.

$[(1 - \delta)\alpha + K\rho]$ for any given screen and light source was devised as follows:

Measurements are made of the illumination at the test plate under three conditions.

Let A = direct light flux only.
B = direct plus reflected light flux (without screen).
C = reflected light only (with screen).

A, the actual direct illumination upon the test plate from the unscreened light source, is measured by attaching the lamp in its proper position to the half of the sphere containing the test plate. The opposite half is removed and a series of black screens are set up between the test plate and the lamp to cut off all light except that directly from the source.

B is measured with the sphere closed, in the usual manner, but with no screen. B — A is therefore equal to the theoretical value of the reflected illumination, ρI, for an empty sphere (except in so far as the lamp and its supports may act as a screen).

C is the value of the reflected illumination as usually measured with screen and is equal to $(1 - \delta)\rho I_d + \rho^2 I$.

Therefore $C/(B - A) = [(1 - \delta)\alpha + K\rho]$ the "screen ratio."

Table V gives a series of measurements made in this manner with a light source having a clear globe, and with the same light source after being incased in an opal globe.

TABLE V.

	A	B	C	C/(B — A)
Clear globe	8.69	36.64	26.38	0.944
Opal globe.............	5.8	28.35	21.61	0.958

It is seen that under the particular conditions of this experiment the opal globe has a slight relative advantage over the clear globe. The results are not open to complete explanation since the relative differences in distribution are only partially indicated by the values of the direct illumination A, at the test plate, as the average intensity of the light flux upon the rest of the screened areas is unknown, and may not be proportional to A. The method as outlined, however, affords a very direct and simple means of investigating special characteristics of the spherical integrator and further data would be of interest.

Another source of error in practical arc lamp photometry which is carefully avoided in German practise has apparently received no attention from the designers of American built spheres. The error consists in a faulty method of determining the "sphere constant."

In the substitution method employed with the sphere the ratio between the known flux of a standard lamp, as separately determined, and its illumination as photometered at the test plate gives the "sphere constant," by which any other illumination as read at the test plate may be converted to terms of the flux or mean spherical candlepower of its source.

This constant[9] must contain in itself all of the factors affecting the relations between light flux and test plate illumination, such as size and surface of sphere, ratio of screened and unscreened areas, absorption of reflected light by foreign bodies such as arc lamp mechanism, screens, etc.

Not only do large lamp mechanisms absorb reflected light, but they screen certain parts of the sphere wall from the test plate, thus changing the ratio of screened and unscreened area.

Therefore, the standard lamp must be read with the arc lamp in position, in order that the sphere constant may contain the proper corrections. But since only reflected light can reach the arc lamp supports when the latter is burning, the same condition must be observed with the standard lamp. That is, none of the direct rays of the latter must strike the arc lamp. The German practise is to place the standard lamp below the arc lamp with a small cap upon the former to shield the arc lamp. The standard lamp must be standardized with this cap in place. In the above-mentioned sphere, however, the standard lamp is placed laterally, where the most intense part of the flux will fall upon the arc lamp parts, and no screen or shield is provided. The arc lamp therefore absorbs a considerable amount of direct light in addi-

[9] Sphere constant $= \dfrac{\text{Flux standard lamp}}{\text{Illumination standard lamp as read at test plate}} =$

$$\frac{4\pi R^2 \alpha I}{(1-\delta')\rho I_{\alpha} + K\rho^2 I} = \frac{4\pi R^2 \alpha^2}{\delta[(1-\delta') + K\alpha\rho]}$$

If R = radius of sphere.
α = absorption coefficient.
ρ = reflection coefficient.
$(1-\delta')$ = fraction of direct light falling on central zone of sphere.
$(1-K)$ = fraction of reflected light absorbed by screens and foreign bodies of all kinds.

tion to the usual amount of reflected light. This increases the sphere constant and the resulting values for the arc lamp are high. An arc lamp which intercepts and absorbs a large proportion of direct light is thus favored over a lamp with smaller or more highly reflecting mechanism.

In this laboratory where many types of arc lamps are employed in the testing of experimental and factory carbons, the correction for the change in sphere constant caused by introducing the arc lamp into the sphere is determined by placing a small screen upon the standard lamp of sufficient size to screen the arc lamp. The standard is read with the sphere empty and then with the arc lamp in position. A factor is thus obtained for the influence of this particular arc lamp upon the sphere constant. The cap is then removed from the standard lamp, and the constant for the empty sphere with known light flux determined. This constant multiplied by the lamp factor previously obtained, gives the correction for the lamp in question.

This method has the great advantage that once the specific factor for each lamp has been determined it is only necessary to determine the constant of the empty sphere thereafter. The latter need be determined but once a day, no matter how many different lamps are being photometered.

Where the primary object is the comparison of different carbons in the lamps, it becomes necessary to determine the transmission and absorption factors of the globes so that the data over long periods of time may be independent of the particular globes in use. Fairly uniform opal globes are selected and standardized separately by incandescent lamps, and the globe factor, together with the corresponding lamp factor, is applied to the particular value of the sphere constant as determined for the day upon which the test is made. By placing an incandescent lamp inside the arc lamp with globe complete, a combined lamp and globe factor may be determined. Since the incandescent lamp has neither the exact position or distribution of the bare arc, the resulting candlepower values are not those of the naked arc, but are proportional to them, and are independent of changing globes.

If the actual illumination of the arc lamp is desired, then the

latter method is inapplicable, and no globe factors should be employed.

A brief consideration will now be given to a source of error in the practical photometry of arc lamps which has apparently been too frequently neglected.

All commercial products are subject to characteristic variations and lack of uniformity, the range and extent of which depends upon the type of product, the inherent difficulties of manufacture, and the standard of quality maintained by the manufacturer. No trustworthy comparison of similar types of competing illuminants is possible without a knowledge of the characteristic range of variation of the particular products under test. The measure of the uniformity of a product is not only essential in determining the true arithmetical value of the property being measured, but also in determining the commercial worth of such value when found. Moreover, the testing laboratory requires a knowledge of the precision measure, or average deviation of the individual samples from their general mean, in order to obtain the most economical and efficient distribution of the time and labor spent upon the test. For example, let it be assumed that the actual variation in physical and illuminating properties of a certain class of carbons is 5 per cent. That is, any single trim will show upon the average a difference of 5 per cent. from the mean value of a large number of such trims. It is then obvious that no matter how exhaustively a single trim may be tested, the result will still differ on the average by at least 5 per cent. from the normal value, and may quite possibly differ by three times the average deviation or 15 per cent. The only possible way by which a closer approximation to the general average value can be secured is not by increasing the accuracy or number of measurements upon a single trim, but by increasing the number of the trims tested. The average deviation of the mean of several independent trims decreases in proportion to the square root of their number. That is, four trims are required to reduce the average deviation one half.

If the actual physical differences possess an average deviation of 5 per cent., the average deviation of the values as measured

will be still greater, because superposed upon the variations due to the actual differences of the carbons from one another, will be the variations due to errors of measurement upon the individual carbons. Assume that the latter has an average deviation of 1 per cent. One has, then, a 1 per cent. average deviation due to errors of measurement superposed upon a 5 per cent. average deviation due to variations in the product measured.

The resultant deviation is not, however, the sum of these two, *i. e.*, 6 per cent., but is the square root of the sum of their squares, *i. e.*, 5.1 per cent. Thus if the two variations are represented as the sides of a right angled triangle, the resultant deviation is equal to its hypotenuse. From this it follows that if one deviation is very small with respect to the other, relatively large changes in its value will have a relatively slight effect upon the resultant deviation. Thus in the example above the errors of measurement may be increased so that their average deviation of 1 per cent. is increased to 2 per cent. and the resultant deviation will only be increased from 5.1 per cent. to 5.38 per cent. Whether the average deviation in measurement of a single trim should be 1 per cent. or 2 per cent. depends upon the relative number of samples which can be tested in each case with the same total cost in labor, materials and overhead expenditure. If it costs no more in a given case to secure an average deviation of measurement of 1 per cent. than of 2 per cent., then the smaller value should be secured, however slight its effect upon the final result may be. Suppose, however, that the time of testing and the number of observations can be cut in half (*i. e.*, from 1-hour to ½-hour) with an increase in the average deviation of measurement from 1 per cent. to 2 per cent. Then if two ½-hour trims can be tested with the same cost as 1-hour trim, the average deviation for the latter is 5.10 per cent. and of the former is $5.38/\sqrt{2}$ per cent. = 3.8 per cent. for the same unit of cost.

The significance of this is more clearly seen by the statement that 26 1-hour trims or 29 ½-hour trims will be required to secure an average deviation of 1 per cent. for the final result, which means a saving of 44 per cent. in the cost of testing to secure the same degree of accuracy in the final result.

The criterion for maximum efficiency of testing in all cases is that the ratio of the resultant average deviation for a single sample, from all causes whatsoever, to the square root of the number of samples which it is possible to test with any given unit of cost, shall be a minimum.

In practise, the evaluation of the various independent sources of variation is somewhat more complicated than is shown by the hypothetical example above quoted and the particular details must be worked out for the special conditions of each laboratory.

However, it serves to illustrate the principles employed in this laboratory in determining the length of tests upon single trims, the number of photometric readings, and the number of duplicate trims. Enough has been said to indicate that in the practical photometry of arc lamps something in addition to the errors of the photometric apparatus must be considered, and that it is quite possible to make very accurate photometric measurements and yet obtain very inaccurate data unless due regard is had for the relative magnitude of the errors of measurement and the variation in the thing measured.

Acknowledgement is hereby made to Mr. R. B. Chillas, Jr., for kindly assisting in the preparation of the manuscript.

DISCUSSION.

Dr. C. H. Sharp: Since the authors of the paper have been kind enough to rake out of oblivion the paper which Mr. Millar and I prepared on this subject, I think I may, with propriety, be permitted to discuss their present paper. Our paper back in 1908 was prepared with a certain end in view; it was to put before the members of this Society what at that time, in this country, was a practically unknown photometric device which we believed to be of very great value. This paper says that it was unfortunate that we did not deal more fully with the theoretical aspects of the subject. We had, however, the idea that the value of our paper to the members of this Society would not be in direct ratio to the amount of mathematics that we could put into it, consequently we did not involve our discussion in any nebulous haze of Teutonic theory (laughter); but tried to get down to the engineering facts of the case as we knew them. Well, a good deal of

water has run under the bridge since 1908, and if our opinions in all respects at the present time do not agree with what we held at that time, I am willing to let it go that we perhaps have progressed and know more now than we did then. As to the facts and data presented at that time, I have no apologies to offer, as I know they were correct and all right as far as they went. I think it is most timely and fortunate that the authors have taken up more fully at this time the theoretical consideration of the integrating sphere and of the errors which may enter into its use. Any considerable discussion of these points at that time might perhaps have been out of place. At the present time such a discussion is needed and I think that we are fortunate to have so lucid and able a one as the authors have presented to-day.

I am impressed more and more with the possibility of the use and misuse of the integrating sphere. In view of the possibility of misuse, for instance, of the translucent screen as shown by the authors and as borne out to some extent in our own experience, I have been for some time inclined to the view that on the whole the opaque screen was the best thing to use, certainly in a large sphere. I think that the paper shows in a very remarkable way the precision with which the sphere will integrate the total flux of light from almost any source whatever when it is used in any ordinarily reasonable manner; and as a guide to the proper use of the sphere, the theory presented is most timely and valuable.

MR. W. F. LITTLE: A number of experiments have been made at the Electrical Testing Laboratories to determine the accuracy as well as the flexibility of the integrating sphere with translucent screens.

TEST NO. 1.—TRANSLUCENT SCREEN.

Position in sphere	Lamp alone per cent.	Extensive reflector per cent.	Intensive reflector per cent.	Focusing reflector per cent.
1 ft. from top..........	100.0	100	100	100
2 ft. from top..........	100.0	100	100	—
3 ft. from top..........	99.5	100	—	100

Test No. 1 referred to above consisted of mean spherical candlepower readings of a tungsten lamp, alone and when equipped with intensive, extensive and focusing prismatic reflectors mounted in various positions in the sphere.

Test No. 2.—A porcelain enamelled parabolic reflector having an asymmetrical distribution was measured in two positions, pointing toward the screen and at 90 deg. to the screen.

TEST NO 2.—PORCELAIN ENAMEL DOUBLE PARABOLIC REFLECTOR.

	Translucent per cent.	Opaque per cent.
Toward screen	103	90
90° to screen	100	100

Test No. 3.—A bare lamp with one side covered with black paper oriented in several positions.

TEST NO. 3.—LAMP WITH BLACK PAPER ON ONE SIDE.

	Translucent per cent.	Opaque per cent.
Toward screen	100	104
90° to screen	100	100
180° to screen	—	100

Even under the above abnormal and adverse test conditions, the above figures show comparatively small photometric errors, and the results are somewhat more consistent with the translucent screen. However, under normal working conditions it is known that the errors introduced by either screen are negligible.

The authors of this paper have stated that the only absorption of light by the lamp or accessory to be corrected for is the absorption of reflected light; no direct light from the standard lamp should fall upon the lamp or accessory. First, the amount of direct light from the standard falling on the lamp or accessory in the 80-inch sphere as used at the Electrical Testing Laboratories is very small and almost negligible. Second, it is the practise at the Electrical Testing Laboratories to cover the lamp housing with a white diffusing substance so as to reduce the absorption to a minimum, or so to mount the lamp that the housing and opaque portions are outside of the sphere; therefore, this criticism can be easily taken care of.

The Laboratories also find a small 40-inch integrating sphere a very valuable and convenient adjunct to the testing of arc lamps. It has been successfully used by lowering the lamp in from the top and placing an opaque screen horizontally in the center of the sphere with a mirror set at 45 deg. to the vertical placed immediately beneath it. The elbow tube of a portable photometer is placed in a small hole in the side of the sphere, so located that

the photometer tube then points at the mirror, which reflects the surface of the sphere immediately beneath the screen, thus using the surface of the sphere rather than the translucent test plate for its comparison surface. A small comparison lamp is placed on top of the screen tip upward. This is used to measure the absorption of light by that portion of the arc lamp which is allowed to remain in the sphere at the time of measurement. Here again the amount of direct light falling upon the arc lamp is very small, as the tip candlepower of the comparison lamp is relatively low. Also the opaque screen is advantageously located for the arc lamp, as the end-on candlepower of the arc is comparatively low.

The integrating sphere has been used very advantageously in the measurement of light loss with various accessories to incandescent lamps. A sufficient number of tests have been made by the "point by point method" on several photometers and spheres to prove the accuracy of the sphere method in securing this value. Lamps of very different reduction factors, and even metal and mirror reflectors, have been measured with very close agreement between the sphere and distribution determinations. In all of this work the Laboratories have used opaque screens merely because they are more convenient; however, it is probable that when used with discretion a slightly higher degree of accuracy is obtainable with translucent screens.

Mr. S. L. E. Rose: This paper is of a great deal of interest to photometrists, and one of the points which I wish to emphasize in the paper which was not brought out in the reading, is the method of test; that is, it is better to test a number of electrodes and take fewer readings on each one than to take a lot of readings on one electrode, if you want an average of what that particular light source will do. That has been the practise at the laboratory which I represent, for some time, as was brought out in the paper[1] at the Chicago Convention of the I. E. S. by Mr. Stickney and myself.

I don't see any mention in the paper of what was used for painting the inner surface of this sphere. I am interested in that and would like to know if the authors made any investigations as to the best paint or material to use for that purpose?

[1] Stickney, G. H., and Rose, S. L. E., Photometry of Large Light Sources; Trans. I. E. S., vol. VI, p. 641.

While it is a little out of the range of this paper, it will probably be interesting to give you one special application that we made of our sphere at the laboratory in connection with some work for the Panama-Pacific International Exposition. It was necessary to know how the light was dispersed from the jewels which are to be used in connection with the illumination of the buildings of the exposition; a number of different makes were submitted with different cuttings and we wanted to know which was the best for the purpose. It would have been an almost endless job to have found out the number of reflections which the jewels gave back from the front faces without the use of our sphere. We simply took one half of the sphere, mounted the jewel at the center on the axis and projected a beam of light through the photometric window, and by means of a small mirror reflected it on to the jewel normally and then made a photograph of that half of the sphere, and we had immediately the distribution of reflected spectra from that jewel; and then we could simply introduce the different jewels which were submitted to us, take a photograph and count the number and see which one was giving the most reflections and the clearest and most intense spectra. By means of radial and circular lines drawn on the photographic print, we could locate them, *i. e.,* we had longitude and latitude and could tell exactly where they were. This work was very convenient, very simple and done in the minimum of time. Fig. A is print from negative of a good jewel and Fig. B is print from negative of a poor one. The circular lines are drawn at intervals of 10 deg.

I am about in the same position as Mr. Little; our sphere is not in constant use, in this way—it might be used for a week steadily and then perhaps stand idle a week, and in that case it gets a coat of dust and we find it is awfully hard to brush that dust off. We use white alabastine and when you go to brush that, it will mix up with the dust and the best way out is simply to paint it over. If we are using it right along, it is probably painted every week; but we might paint it and use it three or four days and then it might set for a month. I might say, though, that practically it is painted every time it is used. I don't want you to understand from that that we paint it every day.

THE CHAIRMAN: Take a piece of new, white, fresh blotting paper, etc.

MR. S. L. E. ROSE: Well, it is not entirely a matter of discoloration, it is more a question of collection of dust and our sphere happens to be in a particularly dusty place, and for that reason we have to paint it oftener than would otherwise be necessary. We use white blotting paper for the internal screens. It seems to me there is a chance for the Committee on Nomenclature to define the different branches of photometry. We hear of precision photometry; this morning we had a paper which spoke of practical photometry, and we have another branch that is called commercial photometry, and the degree of accuracy necessary for one may be entirely out of the question for the others. Mr. E. J. Edwards of Cleveland a short time ago in an article in the engineering department news discussed practical accuracy and wasteful accuracy,—there's the two kinds. Practical accuracy is all we are after in commercial photometry, and the degree of accuracy necessary for precision work would be wasteful in this case.

THE CHAIRMAN: Dr. Middlekauff, what do you use at the Bureau of Standards?

DR. G. W. MIDDLEKAUFF: White alabastine. However, our experience with the sphere has been limited, having been confined almost entirely to the acceptance tests. Although a test of the color absorption by the coating then in the sphere was made incidentally, we were, at the time, more particularly concerned as to the accuracy with which the instrument would reproduce relative values as found by other methods when light sources of the same color were compared. The best results were obtained with an opaque screen reduced in size as much as possible.

THE CHAIRMAN: Would that vary for each size of lamp?

DR. G. W. MIDDLEKAUFF: For our carbon standards, which consist of several groups, each group having a different type of filament, but all having the same size of bulb, accurate relative values were obtained. But for lamps of different sizes of bulb, the area of the screen remaining the same, the agreement in relative values with other methods was not so good.

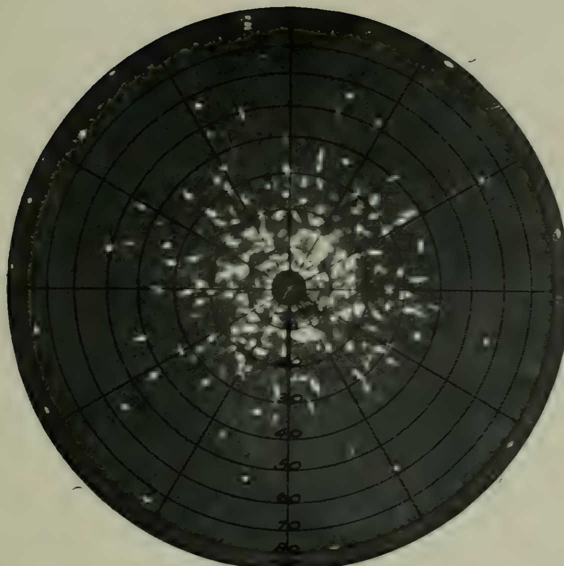

Fig. A.—Photograph of reflections from a good jewel.

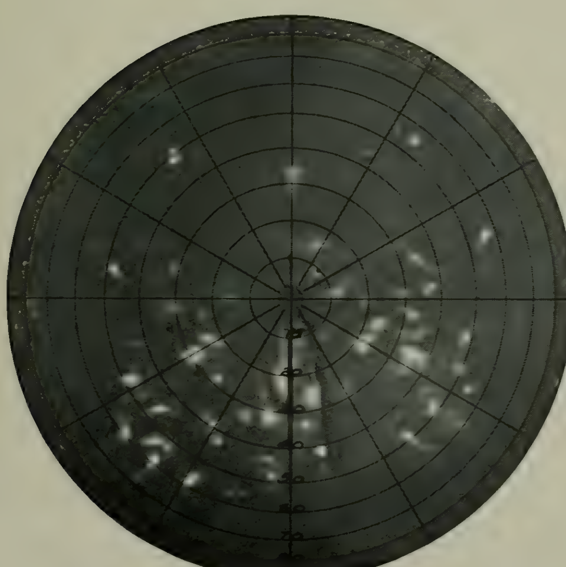

Fig. B.—Photograph of reflections from a poor jewel.

THE CHAIRMAN: What is the size of your sphere?

DR. G. W. MIDDLEKAUFF: Thirty inches in diameter. This was considered large enough for our purpose of comparing incandescent lamps.

In the color absorption test referred to, we used two carbon lamps that matched in color at about 110 volts. When one of these lamps was placed inside the sphere, from which the translucent window had been removed, the other lamp had to be reduced about 10 per cent. in voltage to bring them again to a color match. There being so great a change in color due to selective absorption, it would not be surprising, when lights differing considerably in color (as for example a 4-watt carbon and a ½-watt tungsten) are compared in the sphere, if we should find their relative values quite different from what they would be if the comparison were made outside the sphere by some other method.

In preparing a later coating, it was found by a little experimenting that a very small quantity of Prussian blue mixed with the white alabastine before applying to the sphere reduced selective absorption considerably. With this coating, it is believed the sphere will give quite accurate results in the comparison of differently colored lights.

This simple color test is mentioned in order to emphasize the fact that if the sphere is to be of value in accurate standardizing work in which lamps having widely different colors are to be compared, the character of the coating is equal in importance to the proper design of the instrument.

THE CHAIRMAN: Mr. Cady do you have a sphere?

MR. F. E. CADY: No, we have no sphere. At the Bureau of Standards, when the sphere first appeared, we were very much interested in integrating photometry, but we were in possession of a Matthews type which had proved very satisfactory, and consequently, the sphere did not receive the attention which it would otherwise have had. The engineering department of the organization I am connected with, however, has an integrating sphere of the 30-inch type, I believe. What little experience we have had in attempting to determine the candlepower per incandescent lamp of that sphere has been similar to that of Dr. Mid-

dlekauff; that is, once or twice we have attempted to determine spherical candlepower of lamps with filament windings, different from those of a standard whose mean spherical candlepower we knew, and the results seemed to have some discrepancy. The lamps were afterwards measured on a universal photometer and the mean spherical candlepower calibrated, and we found differences amounting to 2 or 3 per cent. The cause for those discrepancies we did not have time to investigate, but I should like to know whether the authors of this paper, who seem to have confined their work more to arc lamp photometry, have done much in the work with the incandescent lamp and whether they have found that with suitably designed screens, it is possible to take, for instance, an ordinary carbon lamp as a standard, and with that determine the mean spherical candlepower accurately of a lamp having a distribution such, for instance, as that of the old carbon downward light lamp, or in the modern tungsten lamp, those which have filament windings of the spread umbrella type.

MR. R. B. CHILLAS, JR.: There are a few points which may be of interest in connection with equations 2 and 4. In the latter, it is seen that the direct light is equal to the light absorbed, and so disappears as heat radiated from the external sphere walls. Equation 2, the total illumination is equal to the direct light divided by the absorption coefficient, affords a means for obtaining a quantitative value of light wall coverings. The following table gives the ratio of total illumination to that obtained from the source with different reflection coefficients.

Reflection coefficient	Ratio total illumination
P = 0.80	5.00
0.60	2.50
0.50	2.00
0.40	1.66
0.20	1.25

The calculations for minimum screened area were based on obtaining a trigonometric expression for the heights (proportional to the areas) of the two shaded zones, substituting in this the values of the trigonometric functions expressed in terms of

sphere radius, and fractions of sphere radius, differentiating, and equating the first derivative to zero.

The resulting expression is quite complicated and is best solved by successive approximations.

Dr. C. H. Sharp: Regarding the interesting suggestion of using a screen with a mirrored surface toward the lamp, I think the trouble is that it is pretty hard to get a very much higher coefficient of reflection from a mirrored surface than it is from a good, white diffusing surface. It takes a pretty good piece of mirror glass to reflect 80 per cent. of the light and a good white diffusing surface will do as well.

Mr. C. W. Jordan: In the practical working of an integrating sphere it is assumed that the operator has carefully tested the apparatus to eliminate any systematic errors. For example, errors of serious magnitude due to the use of an improperly placed translucent screen can easily be detected by photometering the standard lamp placed in the test lamp holder, after checking in its normal position.

In my opinion the general practise has been to check integrating spheres in this manner and the photometric readings of the standard made to agree when in either position by proper adjustment of the position or translucency of the screen.

One of the sources of error when using the sphere has been due to the relatively greater collection of dust in the lower hemisphere than in the upper. When the light distribution of the lamp being tested differs materially from that of the standard, this error may become serious. Constant repainting becomes necessary to eliminate this error.

I wish to ask what type of photometer was used in making the photometric measurements and the order of its sensibility compared with the sphere errors found.

I think the authors are to be congratulated for their excellent work of individually analyzing the sources of error in the use of a sphere and for the recommendations for their elimination.

Dr. N. K. Chaney (In reply): In replying to Dr. Sharp's very kind comments upon the paper we may frankly say that Dr. Sharp's general position with respect to the intent of his earlier paper is perfectly sound and beyond criticism. We still

venture to believe, however, that it has proved somewhat unfortunate for the development of the use of the sphere in this country, that Dr. Sharp's valuable introductory paper was not more promptly supplemented by further theoretical treatment, in which the then existing "haze of Teutonic theory" would have been made more accessible, and perhaps more intelligible to American workers. The present treatment is based upon a more unified physical conception of the sphere, and we trust will prove less "nebulous" than its Teutonic predecessors.

Where issue was taken with the earlier paper, the case must rest upon the merits of the respective arguments.

Mr. Little, however, has presented certain tables for the apparent purpose of showing that translucent screens are as good or better than opaque screens. So they are, if *particularly* adjusted for *particular* cases. The point made in the paper was that this particular adjustment was not only difficult in practise, but was made at the expense of general integrating power for all-around work. That Mr. Little is not seriously impressed with the showing made by his own figures is clear from his frank admission that they employ opaque screens in all of their work, "merely because they are more convenient." The reasons for the "inconvenience" of translucent screens are thoroughly discussed in the body of the paper.

The "slightly higher degree of accuracy" obtainable by translucent screens, is we believe purely mythical, provided the same amount of "discretion" is used with opaque screens and the proper corrections are made. Where the lamp supports are small or are not introduced into the sphere Mr. Little is correct in assuming that the correction for direct flux from the standard lamp falling upon the lamp supports is negligible. Where the whole arc lamp is introduced into the sphere, as is the practise in the laboratories of the National Carbon Co., the correction for direct flux absorbed in lamps in some cases may amount to as high as 8 per cent. of the reading. In our experience it is simpler to make this correction once for all with each arc lamp used, and then take all regular standard lamp readings with the sphere entirely empty, to correct for daily changes in the walls of the sphere.

Dr. Middlekauff and Mr. Cady, both raised questions concerning the amount of discrepancy likely to occur between different types of incandescent lamps with various filament windings. If the size of sphere and screen, and the approximate distribution curves of the lamps are known this error could be figured out directly by means of a sphere diagram and the formulae in the paper.

In a sphere of reasonable dimensions with proper screens, the variations from this cause should be very small—less than 1 per cent. If the sources are very unsymmetrical it is always important to direct the most intense parts of the flux upon the central unscreened area of the sphere, if the lowest limits of error are to be obtained.

In reply to Mr. Jordan's questions,—a Sharp-Millar photometer was employed. With our standard incandescent lamps upon a line voltage hand-regulated by a rheostat, the average deviation of the mean of 20 readings is slightly less than 0.25 per cent. The data in the paper was the average of two or more independent readers in all cases.

In adjusting screens the test lamp screen should be set up according to the proper formula, and then the standard lamp screen may be adjusted by reading the standard lamp in both positions as Mr. Jordan suggests. It would be possible, however, to have both screens wrong and yet secure identical readings with the same lamp. The real test is the agreement in the two positions of lamps of *different* distribution.

In regard to painting the sphere, attention is called to the foot note upon the sixteenth page of the paper.

The matter of precision in commercial work,—obviously that is to be decided by the needs of the work in hand. It is always proper to find what degree of precision is possible upon any instrument, and then decide how much of that precision is required for any particular purpose.

NEW DEVELOPMENTS IN THE PROJECTION OF LIGHT.*

BY L. C. PORTER.

Synopsis: This paper deals with the theory of the projection of light. It shows different methods of concentrating light into a beam and mentions the different factors which must be taken into consideration in the design of lenses, reflectors and light sources for light projection. The theory is followed by a short description of the practical application of the new focus type tungsten lamps to headlight service, signal work, navigation, stereopticon lanterns and advertising lighting.

The concentration of light into beams for projection purposes has been a field of experiment for many years. Probably one of the best known early applications of light projected to a distance, and one which to-day is playing an enormous part in the struggle for supremacy raging in Europe, is that of the naval searchlight. Here the light generated by a powerful arc lamp has been used largely for defence, *i. e.*, to show up attacking torpedo boats before they can get within striking distance and discharge their deadly "whitehead."

Another old and familiar application is in stereopticon work, largely for illustrating lectures, etc. Headlight service is another common use, the light being projected to a distance for a double purpose: (1) to act as a warning of the approach of a train to trespassers, yardmen, etc., (2) to illuminate obstructions on the right of way, or whistle posts, etc. Until recently the oil lamp was the most widely used equipment for this class of service.

That these applications of projected light were rather limited was due largely to two reasons. Powerful searchlights, such as arc and calcium, were expensive, complicated and required expert attention; while the oil lamp was not powerful enough for various other applications.

When the incandescent lamp was developed it was realized by Mr. G. H. Stickney that here was a possible light source for

* A paper read at a meeting of the New England Section of the Illuminating Engineering Society, November 10, 1914.

various other forms of projectors; not so powerful, simpler and more economical than the arc, and yet of greater capacity than the oil light. Under Mr. Stickney's direction, a thorough study of this field is being carried on at the Edison Lamp Works of the General Electric Company.

Before taking up the applications of incandescent lamps in particular, to projection work, I will review briefly some of the fundamental principles pertaining thereto. Assume, for example, that each ray of light emanating from a light source is of 100 candlepower intensity. If one of these 100 candlepower

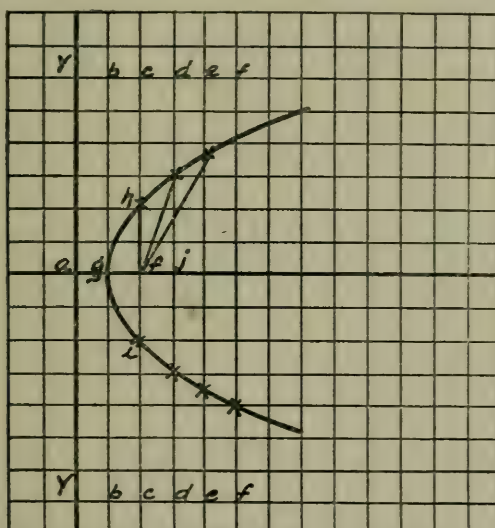

Fig. 1.—Diagram showing construction of the parabola.

rays be redirected so as to coincide with another, the result is 200 candlepower in the latter direction. Similarly, adding together many rays from a low candlepower source, produces a beam of many times the intensity of the original light.

There are two general methods of accomplishing this: one is by refracting the light rays with transparent lenses; the other by reflecting the rays with opaque reflectors. In each case, to obtain the best results, the light must all originate as nearly as possible from one point. The smaller this point, the more powerful will be the beam obtained. All light rays which fall on a

convex glass lens will be bent or refracted as they enter the glass. They will be turned again as they leave the lens, those originating at the principal focus finally emerging in parallel rays. Rays of light originating at the focus of a parabolic reflector[1] will be reflected in parallel lines. Thus, either apparatus produces the beam of the so-called "searchlight." Fig. 2 illustrates this, showing the cross section of a convex lens and a parabolic reflector, indicating the paths of the light rays.

As already mentioned, the smaller the dimensions of the actual light source, the more powerful and narrower will be the beam obtained. In other words, the greater the departure of the light source from a theoretical point, the more will the rays be scattered. Consider, for example, a spherical light source, having its

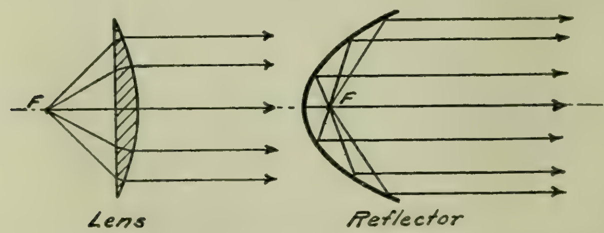

Fig. 2.—Diagram showing projection of light rays from a point source by a convex lens and a parabolic reflector.

center at the focus of a convex lens, Fig. 3. A light ray *a* originating at the focal point of the lens will be turned parallel to the axis; a ray *b*, originating at the surface of the sphere will be similarly bent in passing through the lens. This will bring it below the horizontal; in other words scatter it. The further away from the focus the light originates, the greater will be the divergence. Thus, it becomes evident that the smaller the light

[1] A parabolic reflector is a highly polished surface so formed that all light rays emanating from a certain point called its *focus*, will be reflected in parallel lines. Such a surface is formed by rotating a parabola around a horizontal axis through its focus, thus forming a surface of revolution.

A parabola is the path of a point moving in such a manner as to be always equidistant from a fixed point (called the focus) and a fixed straight line (called the directrix)—see Fig. 1. The mathematical formula is $Y^2 = 4px$, where Y = half of diameter; x = depth; p = focal length of the parabola. To construct a parabola, take a piece of cross section paper; assume a directrix YY; assume a focal length gf and let, $ag = gf$. To find where the parabola cuts bb, take a compass and using ag as a radius and f as the centre, strike an arc till it cuts bb at the point g, which will be on the parabola. Similarly, using af as a radius and f as a centre, another point h on the parabola may be obtained, etc.

source, the more nearly parallel will be the rays; hence the more powerful the resultant beam. The same thing holds true for parabolic reflectors.

It is not practical to produce an absolute point source of light: hence, beams from even the most highly concentrated light

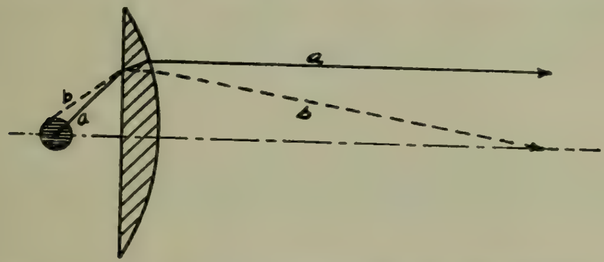

Fig. 3.—Diagram showing projection of light rays from a spherical source by a convex lens.

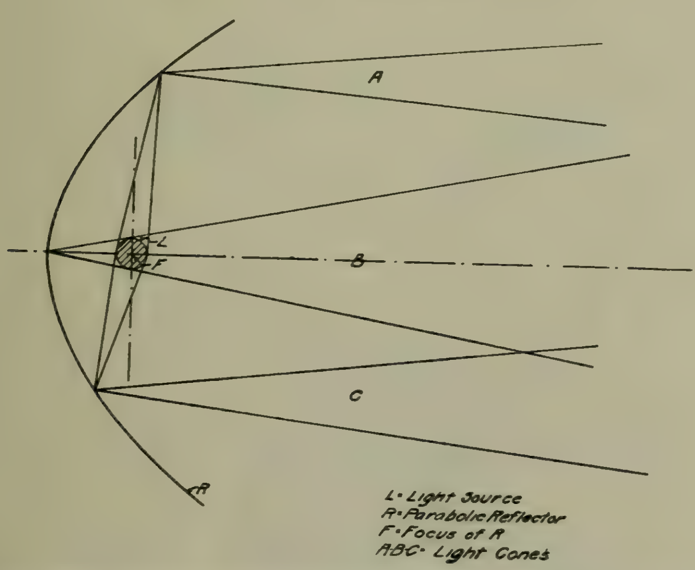

Fig. 4.—Illustrating cones of light from spherical light source in parabolic reflector.

sources—such as the crater of a small arc—will have a spread, depending in amount and direction upon the size of the source and the focal length of the lens or reflector. For example: assuming that we have a spherical light source, the projected beam will be

round and have a maximum spread limited in the distance by two rays *a* and *b* shown (Fig. 4) striking the center of the reflector and tangent to the sphere. The spread from all other points of the lens or reflector will be decreasing towards its edge. Each point of the reflector will receive a set of extreme tangent rays; hence each point emits a little cone of light. The sum of all these cones make up the whole beam, which, therefore, actually consists, up to a certain point, of converging and diverg-

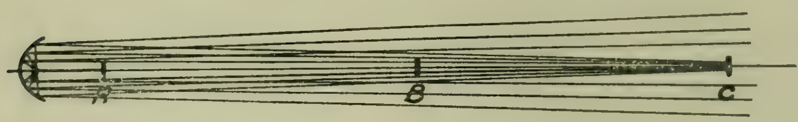

Fig. 5.—Diagram illustrating actual beam from searchlight.

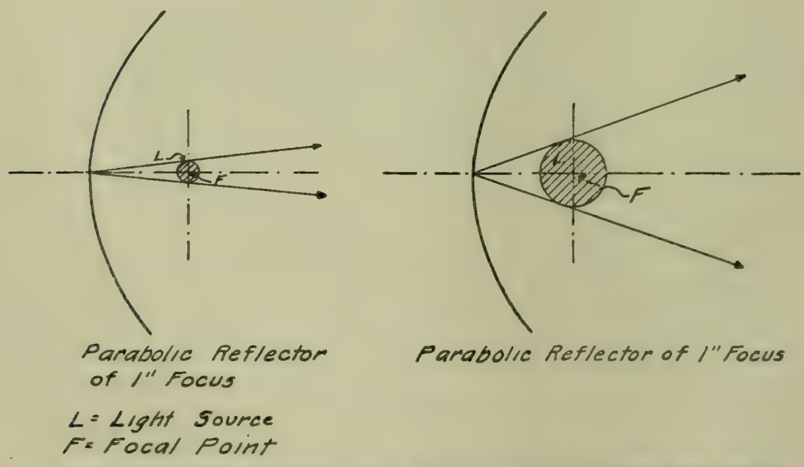

Fig. 6.—Diagram showing maximum spread of beam from large and small light sources in the same focal length parabolic reflector.

ing rays, which at some distance cross and all become diverging —as shown in Fig. 5. In the same reflector the maximum spread from a large light source will, therefore, be greater than from a small light source, each being located at the focus, Fig. 6. If the same size light source is used in a long focus lens or reflector, the spread will be less than in one of short focus (Fig. 7). The shape of the resultant beam depends upon the shape of the light source. For example, an incandescent lamp having its filament

in the form of a helix with its major axis greater than its diameter would throw an elliptical beam, because the spread along its axis would be greater than across its diameter.

To demonstrate the enormous effect of the size of the light source upon the intensity of the resultant beam, I had five lamps made, all of the same candlepower (32) but of varying filament concentrations (Fig. 18). Each of these lamps was focused in a parabolic reflector 11 inches (27.9 cm.) in diameter and of

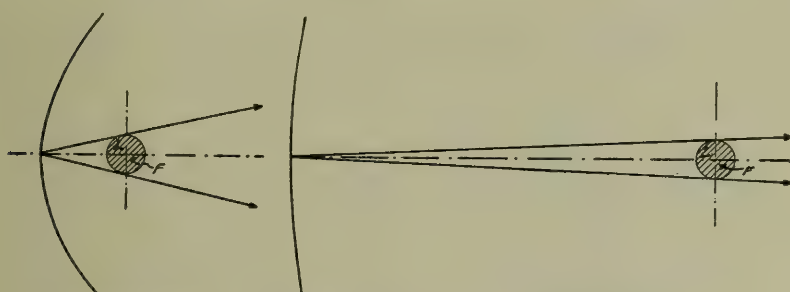

Fig. 7.—Diagram showing maximum spread of beam from same light source in short and long focus parabolic reflectors.

5-in. (12.7 cm.) focal length. The maximum beam candlepower measurements were as follows:

Lamp	Beam cp.
32 candlepower 240 volt carbon, regular	268
32 candlepower 240 volt carbon, stereopticon	555
32 candlepower 120 volt carbon, stereopticon	1,400
32 candlepower 40 volt, tungsten stereopticon (special lamp)	3,335
32 candlepower 6 volt, tungsten stereopticon (special lamp)	3,600

A concentrated light source out of focus may give poorer results than a non-concentrated light source. Consequently, it is of extreme importance to focus the light source exactly. Practically all projectors have some means furnished to accomplish this. To illustrate the importance of accurate focusing I measured the maximum candlepower of the beam of a headlight (consisting of a 16-in. parabolic reflector of 3-in. focus) equipped with a 6-volt, 36-watt tungsten headlight lamp.

This lamp has a filament concentrated into a cylinder 1.5 mm. in diameter by 3 mm. long. The light source was located ¼ in. (25. mm.) back of the focal point and moved forward through it to a point ¼ in. ahead, in 1/16 in. (6.2 mm.) steps. The resultant maximum foot-candle intensities 100 ft. from the headlight are shown in Fig. 8. Fig. 9 shows the maximum spread from reflectors of various focal lengths with different sized light sources. If the light source is moved too far ahead or back of the focus, a dark spot occurs in the center of the beam. If the light source is above the focus the beam is thrown down; if below, the beam goes up; to the right the beam is thrown to

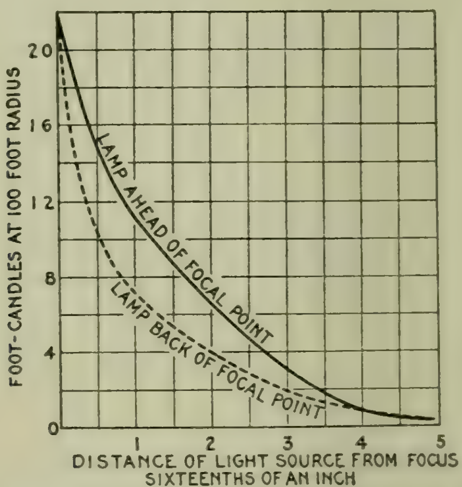

Fig. 8.—Curve showing change in maximum intensity of beam from an incandescent headlight (consisting of 16-in. silver-plated parabolic reflector of 3-in. focus equipped with a 6-volt, 36-watt, tungsten headlight lamp) with a change in the position of the light source.

the left, etc. Fig. 10 shows the distribution curves of the above-mentioned equipment with the light source located at the focus, ¼ in. back of it and ¼ in. to the side of it.

It has been shown that a concentrated light source can be made to produce a powerful beam, either with a lens or a reflector. In some instances lenses are in use; in others reflectors. Naturally, the question arises as to why lenses are used in one case and reflectors in another; what are the advantages of one over the

other, etc. In general it may be said that lenses or accurately ground glass reflectors, such as mangin mirrors, are preferable where stray light is objectionable—such as for stereopticon lanterns; and where extreme accuracy is necessary—as in large

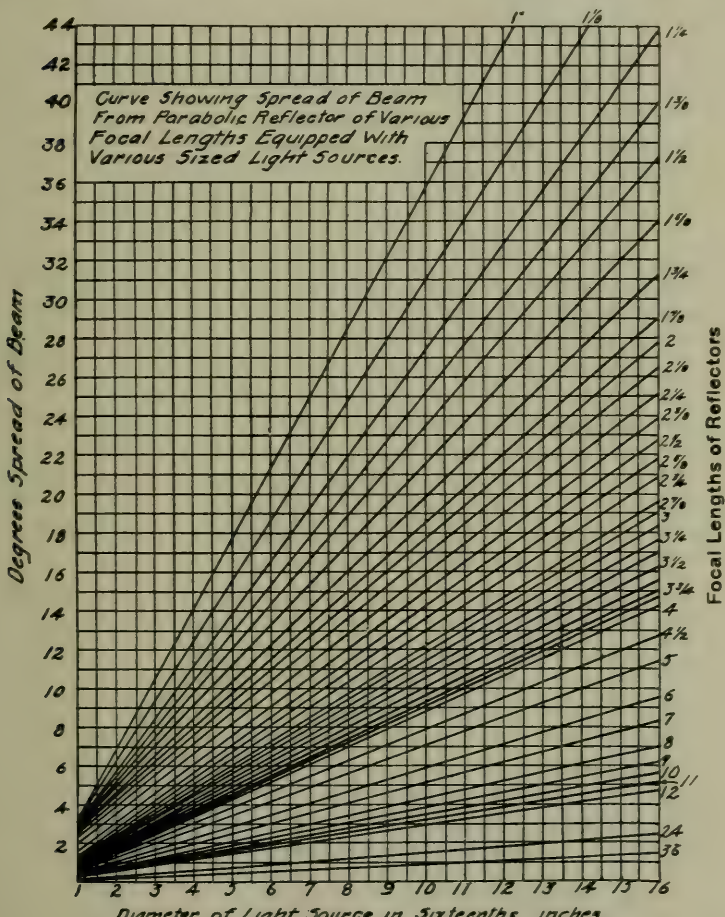

Fig. 9.—Curve showing spread of beam from parabolic reflectors of various focal lengths equipped with various sized light sources.

searchlights. Such work warrants the more accurate and more expensive ground glass lenses and mirrors. On the other hand, such applications as headlights do not require very accurate distribution of light; in fact, a little stray light in the immediate

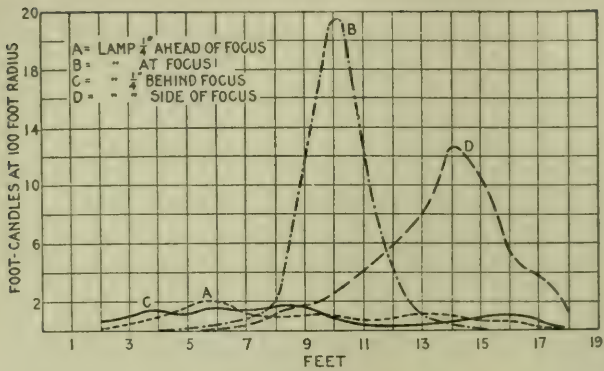

Fig. 10.—Distribution curves across beam of a headlight (equipped with a 16-in. silver-plated parabolic reflector of 3-in. focus, and a 6-volt, 36-watt ,single vertical helix tungsten headlight lamp) with lamp in different positions.

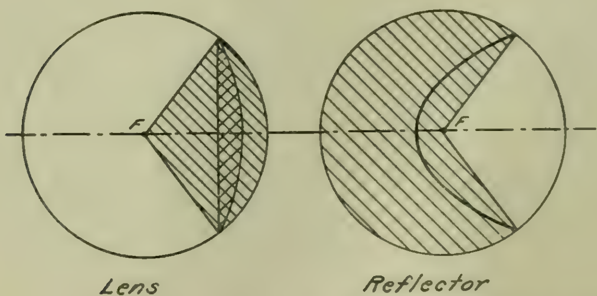

Fig. 11.—Diagram showing amount of light flux from a point source utilized by a convex lens and a parabolic reflector of equal diameters.

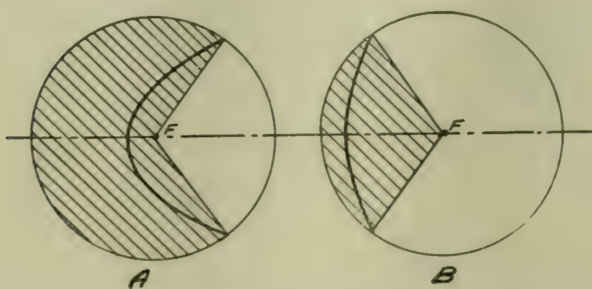

Fig. 12.—Diagram showing amount of light utilized by a short focus and a long focus parabola of equal diameters.

foreground is desirable. Nor does this class of work warrant expensive lenses. For this service metal parabolic reflectors are excellent.

The parabolic reflector has the advantage of covering and utilizing a greater percentage of the total light flux. For example, Fig. 11 shows a reflector and a lens of the same diameter. The shaded portion illustrates the total light falling on and being redirected by each, showing a considerably greater percentage for the parabolic reflector. It is evident from the figures that by placing the focus deeper in the parabola—or in other words, using a reflector of shorter focal length—a still greater percentage of the total light flux could be utilized.

A short focus parabola is a deep curve, while a long focus one is shallow. Fig. 12 shows two parabolas of equal diameter, but different focal lengths, *A* being short and *B* long. *A* reflects the greater percentage of the total light emitted (Fig. 13).[2]

On the other hand, a short focus reflector requires a lamp of small diameter, while the long focus allows a larger bulb—hence a higher candlepower lamp—to be used. Assuming the size of a light source to remain constant, an increase in its candlepower will produce an equal increase in the intensity of the resultant beam.

From the figures shown the thought occurs, Why not combine a parabolic reflector and convex (or condensing) lens, and thus

[2] This curve sheet is made up to indicate the various mechanical properties of the parabola and can be best illustrated by an example: a reflector for a headlight; 16 in. in diameter, 3-in. focus; desired first to find the total depth of the parabola *x*. This is done by using the lower left hand series of curves and drawing a horizontal line from *a* intersecting the 16-in. diameter curve at *b*; from *b* the perpendicular is dropped to the line of abscissas. It is then found that the depth is slightly over 5¼ in. (13.3 cm.). It is now desired to find the angle alpha which is one half of the total angle from the focal point to the edge of the parabola. This is done by using the upper right hand series of curves and drawing a horizontal line from *d*, intersecting the 16 in. (40.6 cm.) diameter curve at *e* and erecting a perpendicular intersecting the top line of abscissas at *f*. The angle alpha is then found to be 106½ deg. In estimating the efficiency of the parabola, it is very desir able to know how much of the total light flux emitted by the lamp strikes the parabola. This is done by projecting the line *ef* until it intersects the *cosine curve* running diagonally across the sheet. Upon the point intersecting *g* a horizontal line is drawn intersecting the right hand line of the ordinates at 0.65. This means that 65 per cent of the total light is useful. Not only is the curve sheet useful for finding the particular values mentioned above, but it will also serve to help estimate the dimensions of the parabola to perform various functions.

Provided the diameter and depth of the parabola can be readily measured, the focal length can be easily obtained, as well as the angle alpha. (By courtesy of Mr. K. W. Mackall, General Electric Company, Schenectady, New York.)

direct into one beam 100 per cent. of the light flux generated? This could not be done, for the following reason. Light coming from the focus of the lens would be refracted in parallel rays; coming from some other point, it would be scattered. Place a lens in front of a parabolic reflector, and the reflector becomes

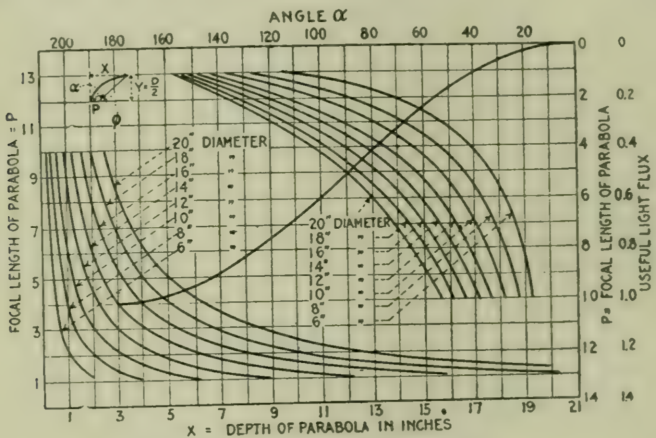

Fig. 13.—Physical properties of the parabola.

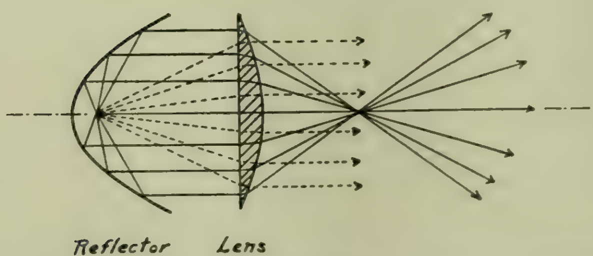

Fig. 14.—Diagram showing effect of combining a convex lens and parabolic reflector on light rays from a point source.

the light source for the lens, giving a result similar to that shown in Fig. 14. This has been done where a double beam is desired; one narrow and powerful to reach far ahead, the other wide to pick up objects to one side in the foreground—such as whistle posts, etc., in railway service. Lenses and reflectors are, however, frequently combined in this manner: A convex lens is backed by a mirror in the form of a sphere, having its center at the light

source. Such a spherical mirror will re-direct the light, throwing it back through the light source; thus increasing its apparent intensity. Where incandescent lamps are the light sources, the spherical mirror has an additional advantage. By throwing an inverted image of the filament back on the filament itself, the apparent light source becomes more nearly solid, resulting in a more uniform field.

The first incandescent lamps to be commercially applied in considerable use to this work were the old carbon stereopticon lamps of 128, 200 and 260 watts capacity. These lamps had a conical shaped spiral filament and operated at an efficiency of 3.94 watts per candle. Similar lamps of 64 and 128 watts, at 4 watts per candle, were also put out for street car headlights. The filament was wound in a conical spiral, in order to concentrate it as much as possible (Fig. 18).

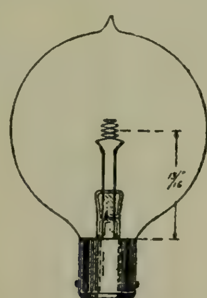

Fig. 15.—Focusing headlight lamp.

With the introduction of the drawn-wire tungsten filament lamp, operating at a much higher efficiency than the carbon, and obtainable in considerably greater capacities, the scope of the incandescent projector was enormously enlarged. Not only were these lamps available in much higher wattages than carbon, but the filaments could be concentrated to a much greater degree. Operating at a remarkable advance in efficiency over the carbon, further increased their advantages for this class of service. The production of lamps varying from very low to very high candle-powers offered light sources for almost all forms of projection apparatus.

The first field to apply these lamps was that of automobile

headlights. Six-volt lamps of various candlepowers were developed. The filaments of these lamps took the form of a double helix, *i. e.*, screw shaped, in order to give sufficient spread to the beam to cover the road (Fig. 15). The first large lamp made was a 100-watt, 110-volt stereopticon lamp. The filament of this lamp was wound into a closely coiled helix of small diameter and this helix in turn rewound in such a manner as to concentrate all of the light source of the lamp into a cylinder 8 mm. long by 8 mm. in diameter. This lamp is made in a round bulb 3¾ in. (9.52 cm.) in diameter (Fig. 16). Lamps of this type are commercially available in 100, 250, 500 and 1,000 watts capacity, though the latter lamp has not yet been standardized. Experimental lamps

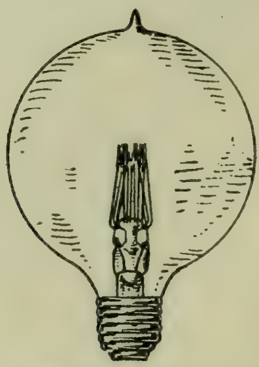

Fig. 16.—Focus type tungsten-filament stereopticon lamp for 105-125 volt service.

have been made of considerably higher wattage, and at a very high operating efficiency.

The low-voltage lamps can be made with much more highly concentrated filaments, due to the short thick wire used and, therefore, require less wattage to produce the same beam intensity. The filament of a 6-volt, 108-watt headlight lamp occupies a cylinder 2.5 mm. in diameter by 5 mm. long; while that of a 100-watt, 110-volt stereopticon lamp is 8 x 8 mm.

The field of application of these concentrated filament lamps is very large, starting with the low voltage lamps of which an enormous number is used for headlight service (headlights for all sorts of purposes, particularly automobiles, motor boats, aeroplanes, fire fighting apparatus, etc.); and as portable lamps for

small searchlights, small spotlights, theatres, etc. At first one thinks of a 6-volt battery lamp as of rather small capacity, yet several thousand 6-volt lamps are now in use by one of the large railroads for headlights. The lamps are 108 watts capacity, 150 candlepower, and have a highly concentrated filament. In a 20-inch (50.8 cm.) silver plated parabolic reflector, this type of lamp produces a beam of over 900,000 candlepower—sufficiently powerful to discern objects over 2,000 feet away.[1]

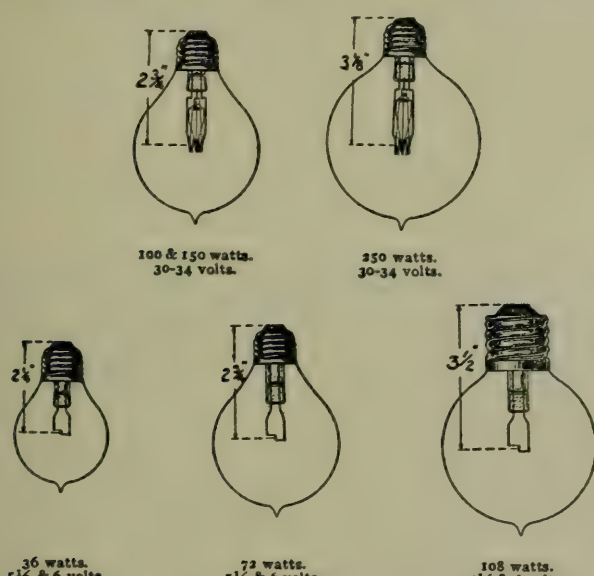

Fig. 17.—Tungsten-filament, focus type headlight lamps.

Many locomotives are already equipped with 30-volt generator sets, with which arc headlights were previously used. Thirty-volt concentrated filament lamps have been developed of 100, 150 and 250 watts capacity, to enable the operation of incandescent headlights from these generators (Fig. 17). A special lamp of 1,500 candlepower in this voltage is also available, to meet the rather extreme law in some states, requiring locomotives to carry headlights of 1,500 unreflected candlepower.

[1] Schrugham J. G., Electric Headlights; *Journal of Electricity, Power and Gas*, February 7, 1914, p. 125; Minick, J. L., The Locomotive Headlight; TRANS. I. E. S., vol. IX, No. 9.

The incandescent head-lamp has many advantages, such as ease of control, steadiness of beam, simplicity, reliability, etc., which make it especially applicable to this class of service. Various tests have shown that for equal beam candlepowers the incandescent headlight will pick up objects at considerably greater distance than the arc headlight. This is probably due both to the color and steadiness of the light from the incandescent lamp.

Another large field of application for the low volt concentrated filament lamp is in signal work. The railroads are experimenting with the so-called "daylight position signal." The indications of these signals are given by three rows of lenses at 90, 45 and 0 deg. positions. Each lens is backed by a low candlepower concentrated filament lamp and either the 0, 45 or 90 deg. row is lighted, depending upon whether the signal is stop, slow or proceed. It is claimed that even under the trying conditions of looking at the signal toward the setting sun it is visible from a greater distance than the regular semaphore blades. The daylight position signal eliminates moving semaphore blades and prevents possible mistakes through color blindness of engineers, or color changes due to atmospheric conditions. If the trial installations prove as satisfactory as expected, this method of signaling should be widely applied.

Another field in which the lamps have been used is for lightships and range lamps having a low candlepower, highly concentrated filament, backed by a silver plated parabolic reflector. Lights from these lamps have a distinctive color and sparkle and are visible at great distances.

Experiments are being made with small lamps and dry batteries for heliograph signals. Lamps of about 0.5 candlepower, 2.7 volt, backed by 5-in. (12.7 cm.) mirrors, operated by small dry batteries have successfully been read at night without the aid of glasses from a distance of 12 miles (19.3 km.).

The big commercial demand for focusing filament lamps, however, will probably be in the 105-125 volt class. Here the number of applications is very large. I will simply touch on some of the principal ones. Chief of these at present is stereopticon work. An incandescent lamp makes a stereopticon lantern safe, simple and clean, so that it can be operated anywhere, by any-

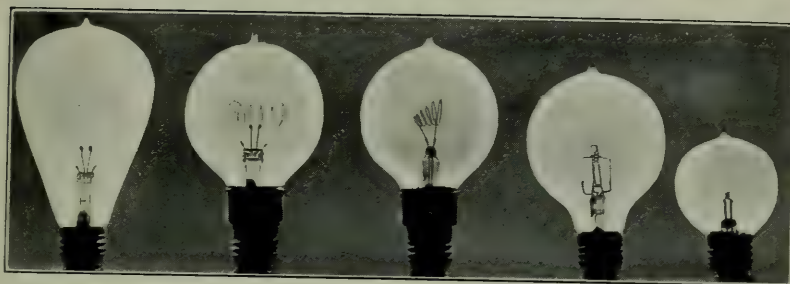

Fig. 18 (Reading from left to right).—1—32-cp., 240-volt regular carbon lamp; 2—32-cp., 240-volt carbon stereopticon lamp; 3—32-cp., 120-volt carbon stereopticon lamp; 4—32-cp., 40-volt tungsten-filament stereopticon lamp; 5—32-cp., 6-volt concentric helix tungsten-filament lamp.

Fig. 19.—Building front illumination with one 500-watt tungsten stereopticon lamp in 16-in. parabolic reflector of 3-in. focus.

Fig. 20.—Morgan memorial library, Hartford, Conn., illuminated by four 500-watt tungsten stereopticon lamps in parabolic reflectors located across the street.

Fig. 21.—Billboard lighted by one 500-watt tungsten stereopticon lamp in a 16-in. parabolic reflector of 3-in. focus 250 ft. away.

body. A lecturer is not bothered by the operator forgetting to regulate the feed of his lantern, or by the humming or hissing noise inherent in most of the powerful lanterns; in fact, numerous advantages are gained. For the small lantern, sign projector, etc., the 100-watt lamp is ample. For larger lanterns, such as used in small auditoriums and lecture rooms, the 250-watt is preferable. As these lamps are in the same size bulb, they are interchangeable. The 500 and 1,000-watt stereopticon lamps have been developed to take care of larger lanterns. The lamps should always be used with a spherical mirror, thereby increasing the intensity on the screen at least 30 per cent. and also obtaining a more uniform field. The 500 and 1,000-watt lamps are also satisfactory for small moving picture machines.

No satisfactory lamp is yet available for the large commercial motion picture machine, but lamps of very high candlepower are being experimented with, and it is hoped these used with the proper mirrors and condensing lenses will be successful. Their adaption to moving picture machines would largely reduce the fire risk, and eliminate synchronism troubles in motion picture theatres supplied with alternating current.

For playhouse lighting, focusing filament lamps have been successfully used as floodlights and for lighting drops. The ease and steadiness with which they can be dimmed any desired amount enables sunrise and sunset effects not practical with other illuminants.

A field which is just opening and promises to be large is that of floodlighting of building surfaces and painted signs. Many buildings, beautiful pieces of architecture, cease to attract with the approach of darkness, simply because they cannot be seen. Figs. 18, 19, 20 and 21. By the use of 500-watt tungsten stereopticon lamps and parabolic reflectors, it is a fairly easy matter to flood them with light from the roofs of neighboring buildings, or any convenient location, and make them stand out in all their beauty after dark; causing them to appear even more conspicuous than in daylight, by contrast with the surrounding darkness. Frequently signs painted on water tanks, walls of buildings, chimneys, etc., or regular billboards, are so located as not to be easily accessible to current supply or are difficult to wire. These can

be effectively lighted at night by projecting light onto them from distances of several hundred feet; thus greatly lengthening their advertising value at a low cost. At night they become more attractive than during the day, and can be read from considerable distance. Advertising banners, flags, etc., have been similarly lighted to advantage. This is a most excellent field for central stations. The load is steady, the hours of burning are long, and the installation is simple. The class of service does not conflict with the regular electric sign. Flood lighting is generally applied to such signs as are visible from other and more distant portions of a city than the electric sign on the main business street; and on account of its low installation cost and easy maintenance, it can often be installed where it would be impossible to sell a regular electric sign.

ART AND SCIENCE IN HOME LIGHTING.*

BY GEORGE W. CASSIDY.

Synopsis: Some of the factors and conditions which influence the design of lighting systems for moderate priced suburban or country homes are discussed in the following paper. The author suggests methods for lighting various rooms of homes costing from $5,000 to $15,000.

The proper lighting of the home has become a very important subject in recent years from two standpoints, namely, the esthetic and the scientific. A broad and comprehensive knowledge of both these phases is required if satisfactory results are to be obtained in practise.

As to the different points governing good lighting of the home, almost as many expert opinions have been expressed as there are different kinds of lighting, each statement being based on the individual point of view of the lighting expert.

The illuminating engineer whose training has been essentially scientific, although he may have the artistic temperament, when it is necessary to compromise between what is scientific and what is purely esthetic in a given case, is almost sure to tip the scales in favor of the scientific. The same argument applies vice versa to the architect or designer whose training leads him to give the greater weight to the esthetic side.

I doubt whether in most cases the best results can be obtained except by the cooperation of the architect and the lighting engineer. For instance, a lighting engineer asked me to cooperate with him in designing a table lamp which should be essentially beautiful and at the same time efficient both for reading and as medium for general illumination. It was specified that the lamp should be equipped with a 250-watt distributing, mirror reflector for the indirect light and four direct lamps properly shielded by diffusing glass for reading; also the indirect equipment should be outside the field of vision of a tall person coming into the room. Our first attempt was a flat failure from the artistic side, as the silk shade portion had to be made on the graceful curves and gen-

* A paper read at a meeting of the New York Section, Illuminating Engineering Society, December 10, 1914.

erous proportions of a barrel. A number of compromises were then made, the most important being the reduction of the size of the lamps from 250 watts to 150 watts. This change so reduced the dimensions of the shade that a well designed lamp was possible both from the artistic and scientific standpoints.

To illuminate a home properly, the lighting must be considered from the esthetic, physiological, psychological and economical standpoints. From that old saying, "a man's house is his castle," one knows that every man desires to have his home as beautiful as his means will afford and as his taste dictates. Therefore the primary requirements is that the lighting should be esthetically correct; the fixtures should be designed to harmonize with the decoration of the respective rooms. Most homes to-day have lighting fixtures which are esthetically correct.

In taking up the second consideration one is confronted with an entirely different condition. How many homes even approach being correctly lighted from the physiological standpoint? The change in the type of illuminants in the last few years has placed a much greater emphasis on the physiological side of the question not only from the increase in intensity of the light but also from the decided change in color. Instead of the soft yellow light of the carbon lamp, one must now contend with the hard, cold white light of the tungsten lamp.

This point was particularly forced on my attention while I was walking through some of the prominent streets of my home town when I saw the large number of houses which were lighted with brilliant and glaring tungsten lamps. If these lamps were not of the frosted, ball type, they were shielded by some form of frosted shade which is a good medium to show just where the filament has its brightest point.

From an ocular hygienic standpoint, it is very easy to understand why a great majority of the people of to-day are compelled to wear glasses and why there is so much suffering from eyestrain.

The third consideration, the psychological, is also of great importance for it has to do with the effect light has on the mind. I will not take time to go deeply into this phase of the subject. However, there is no question that certain kinds of lighting will,

as the saying goes "get on one's nerves." For illustration, the improper use of semi-indirect or indirect lighting in the home. One's first impression on entering a room lighted by either of these systems is the lack of glare; but after sitting in the room for a while one often wonders why the ceiling seems so low; or why a beautifully carved table or chair does not seem to have the proper perspective, for the slight shadows they cast are from an unnatural angle; there is a spectral look to the objects in the room. In other words, the whole room looks flat; it lacks the correct balance of light. I will later explain this effect in a specific case.

It is also a known fact that color is an important factor from the psychological standpoint and applies particularly to white lights. Just how the nerves or mind are affected is a question that comes within the province of the psychologist. Personally, I know of a number of cases where the effect of white lights, I mean white light of the ordinary tungsten lamp, concealed in ground glass shades, has caused the person to be depressed or have the blues.

In lighting a house the problem should be taken up first from the practical side and not the artistic or esthetic. Often the outlets are placed without regard to the purpose for which the room is to be used. It is very important to study the specifications carefully, to learn the area of the room, the height of the ceiling, the general decorative scheme and particularly the purpose for which the room is to be used.

Knowing the use of the room, one can readily decide upon the foot-candle intensity, place the outlets, and determine the proper amount of wattage, etc.

I have tried to describe in a general way the most important principles which should be borne in mind when a problem of home lighting is being considered. For a more comprehensive understanding of a number of the points already mentioned, it will be better to mention the actual conditions encountered by giving a particular case: the proper lighting of a modern suburban or country house costing from $5,000 to $15,000. Such a house usually has an entrance hall, living room, den or music room, dining room, kitchen and pantry on the first floor and sleeping and bath rooms above.

Entrance Hall.—Frequently this room is given little or no attention as far as correct lighting is concerned—"just a light," many owners seem to think, is sufficient. And yet one's first impressions of a home are obtained from the appearance of this room. Very often the first thing to be seen is the typical hall lantern with its glaring lamp. I do not think I exaggerate when I say that a very large percentage of all houses to-day have halls lighted in this manner.

Suppose the following specifications for this hall: dimensions 16 ft. long, 10 ft. wide and 9 ft. 6 in. high, with colonial treatment. The stairway is situated at the rear end. The woodwork is to be white with medium colored walls and light buff ceiling.

The first question to determine is the approximate intensity of the illumination required. There should be an intensity of at least 1 to 1.5 foot-candles. Uniformity here is not at all necessary; however, there should be no dark corners. The amount of light required will be determined by the color of walls and ceiling, and the absorption of the glass employed.

Having determined the light intensity, the position of the outlets is the next problem. In this particular case there should be one ceiling and two bracket or side-wall outlets. The ceiling outlet should be in the middle of the room and the side outlets arranged to balance properly. For economical reasons the ceiling outlet should be wired for two circuits; one for the night light and the other for general illumination. For convenience the lamps should be controlled from the second floor as well as from the first floor.

To illuminate this room and stairway efficiently from a single ceiling outlet, it would be necessary to increase the power of the illuminant to a point where the intrinsic brightness would be very annoying. By distributing the lighting units and using smaller illuminants shielded by properly designed shades, made of tinted diffusing glass, or by amber colored lamps, the glare would be reduced to a minimum. With this foundation, the designer or decorator, can readily design fixtures which will harmonize with the period or decoration of the room.

When little thought is given to these scientific principles, the fixture designer's efforts may often be spoiled because the fixtures lose their identity in their environment simply because of excessive glare from the lamps.

Living Room.—In lighting this room, there are several very important points which have a bearing upon the success of the lighting scheme. The first and most important point is this: here the family lives and in the evenings they must live with the lighting provided. In a great many cases this seems to require an effort.

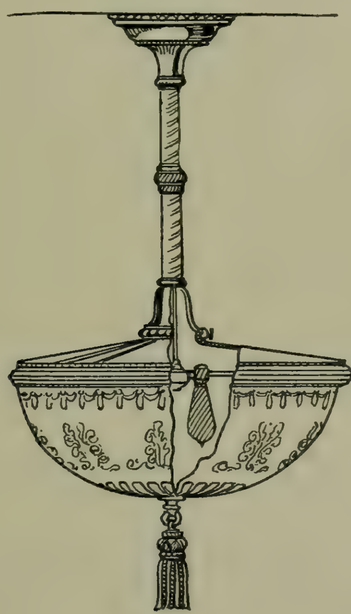

Fig. 1.—Fixture for general illumination in a living room.

Suppose the following specifications are those of a typical living room: dimensions: 24 ft. long, 18 ft. wide and 9 ft. 6 in. high; wood trim of flemish oak; walls a medium brown, and ceiling light buff.

I have already placed emphasis upon the fact that the purpose for which the room is to be used is very important. The living room is used for several purposes; therefore the lighting scheme must have flexibility. In addition to being the library of the

home, it is often used for festive occasions. There are other times when members of the family simply desire to sit around and converse. To meet these conditions it is necessary to supply at least three different lighting arrangements. In placing the outlets the decorative arrangement must not be lost sight of, even though a compromise is necessary. In order to keep the intrinsic brightness reduced to a minimum there should be two ceiling outlets, one in the center of each half of the room. This arrangement will give a more even distribution of light and a decided reduction of glare.

With a light intensity approximating three and a half foot-candles, a high general illumination is assured which will suffice for card playing, dancing and special occasions. For average conditions a one and a half foot-candle intensity will be enough. In order to accomplish this in the best way, each fixture should be wired with two circuits, the higher candlepower lamps on one and those for the lower intensity on the other.

Before considering the type of lighting fixture to be suggested, it will be well to briefly define the three forms of illumination in common use at the present time, namely, direct, semi-direct and indirect.

A direct lighting fixture throws most of its light directly to the floor and walls; only a small percentage of the light reaches the ceiling. A semi-indirect fixture reflects the greater percentage of its light to the ceiling from which it is diffusedly reflected downward; a smaller percentage of the light passes through a glass or translucent bowl. An indirect fixture reflects all the light to the ceiling from which it is diffusedly reflected over the room.

Consider first the usual semi-indirect lighting unit. The height of the ceiling being 9 ft. 6 in., the maximum distance of the top of the bowl from the ceiling cannot exceed 2 ft. 4 in. because with a bowl 6 in. deep the fixture would hang 6 ft. 8 in. from the floor. From the esthetic viewpoint, this type of fixture in this room would be bad practise because the distinctly bright spots over the fixtures would be the most conspicuous points in the room. With a ceiling 11 or 12 ft. high a semi-indirect fixture or an indirect fixture with a luminous bowl can be hung far enough

below to give a wider and more even distribution to the light and thereby overcome the objectionable effects of light spots. This defect could also be softened and the light balance restored by the use of one or more table lamps or by incorporating side brackets in the decorative scheme. These same objections would apply to the indirect unit.

Esthetically, the use of the indirect fixture in the home is incorrect unless designed with a luminous bowl; otherwise, with the opaque bowl, the body of the fixture forms a very sharp contrast with the lighted ceiling.

The most commonly used fixture in living rooms is a direct lighting type of the multiple unit or shower design. The glass manufacturers have put on the market a great variety of shades to be used on fixtures of this type. They have recognized the fact that by artistic etching and tinting, in the ivory tones, they have been able to produce an article which is effective and at the same time eliminates an appreciable amount of the glare, and there is no question but that the results obtained by the use of this glassware is a step forward. These shades should be long enough to conceal the lamp. Considerable caution must be exercised also in the selection of illuminants. If the conditions are such that a high intensity of light is required as in the present case, the filament of the lamp will be visible as a distinctly bright spot on the shade owing to its closeness to it.

I have now described three different types of fixtures and apparently without arriving at a satisfactory result. Therefore a compromise suggests itself: the blending of the desirable features of direct and semi-indirect lighting. By designing a fixture of the glass bowl type, equipped with an opal cover, one may obtain a unit which will transmit a soft diffused light to the ceiling without spotting, while a good percentage of the direct rays will pass through the bowl. By reducing the ceiling illumination and utilizing the direct rays, the effect of flatness in the room may be avoided and the natural perspective and shadows of objects retained. Care must be taken in placing the lamp within the bowl to have the filaments sufficiently distant from the side to prevent the appearance of bright spots and to permit the light to be properly diffused through the glass. Glass afford-

ing a maximum diffusion and the minimum of absorption should be used. This type of fixture will overcome many of the defects which are objectionable from a physiological standpoint.

Artistically and psychologically it is still defective, in that the room lacks color and a correct balance of light. By this latter term I mean a distribution from other sources in the room such as softly lighted lamps on side brackets or portable lamps so arranged or placed as to bring out the important points in the scheme of decoration.

Supplemental lighting is of course more or less extravagant and where economy is essential it can be omitted with possibly the exception of the table lamp.

I have mentioned in a general way, the desirability of the use of color in the lighting of the home. It is regrettable that more emphasis has not been placed on this part of the problem by those interested in artistic lighting and also those who approach lighting problems from the engineering side. I have heard and read statements made by lighting experts that the ideal artificial light is that which most closely resembled natural daylight in color and diffusion. I consider this statement entirely too broad and in need of qualification. Daylight is the ideal light medium in all manufacturing pursuits, office work, draughting, color matching and many other commercial enterprises. I may be making a rather radical statement when I say that daylight as it comes from the heavens is not the ideal light for lighting the home. The really artistic home should be esthetically lighted under daylight conditions as well as under artificial light.

The interior decorator studies his problem from many angles, two of the principal ones being light and color; and if daylight is the ideal light, why does he use so much color in the window hangings, portieres, etc., and at times even shut it out entirely? It is to improve upon daylight, to obtain color and pleasant lighting effects and shadows.

Therefore, if daylight lacks color, and artistic warmth, why should one strive to imitate it for the home. The present illuminants have already reached beyond the limit of good light for home use and need modification for the best results.

There are available several materials suitable for producing

color effects in decorative lighting such as silk, gelatine and glass. I have been informed that one of the large lamp manufacturers has already perfected a method by which regular sized lamps can be made of amber colored glass and put on the market as standard lamps.

I have said that the fixture I have described as the most suitable for the requirements of the living room lacked color. Ophthalmologists and oculists have agreed that amber light is preferable to other colors. By tinting the glass bowl a yellow tone, and by the use of light amber glass lamps or color caps on incandescent lamps giving white light, it is possible to produce the soft warm and hospitable effect so necessary to bring out the real fineness of the decorative scheme of the room.

The practical engineer will in all probability say that such a scheme sacrifices economy. This is true, but economy is of secondary importance when compared with the artistic results and ocular comfort. Ocular hygiene may well be a primary factor in the lighting of living rooms. It is unfortunate that there are so few table lamps on the market to-day which combine the scientific and the esthetic requirements. Many of these lamps are artistic; some few scientific; but a combination of the two is almost wanting.

In order to demonstrate more clearly the important points necessary to be borne in mind when designing an efficient table lamp, I will exhibit a lamp (Fig. 2) which I believe meets the requirements of a living room. It possesses the three essential features of good lighting: first, it is artistic; second, it is efficient as a reading lamp; and, third, it has flexibility. By turning one switch, one may connect indirect light which evenly illuminates the whole ceiling with a soft amber glow. By the turn of a second switch, two more lamps illuminate the silk shade which diffuses a soft light over a large area of the floor. This is necessary to give the correct balance of light in the room. Under daylight conditions most of the light coming through the windows is distributed on the floor and there is a balance between the brightness of the ceiling with that of the floor. This is the natural condition of light direction which mankind has been accustomed to for generations. With a third switch the two remaining lamps

which are utilized for reading purposes may be lighted. These switches also conduce to economy in the use of the lamp. In selecting the mirror reflector for the indirect light equipment, I have taken the concentrating in preference to the distributing type, because the amber colored disk will distribute to a certain extent. Care must be taken to prevent the light distribution from going beyond the stop line. In most rooms this would be at the picture moulding; and, where this is omitted, the proper line would be at the junction of the wall and ceiling. In the arrangement of the direct lamps the filaments are so placed that the

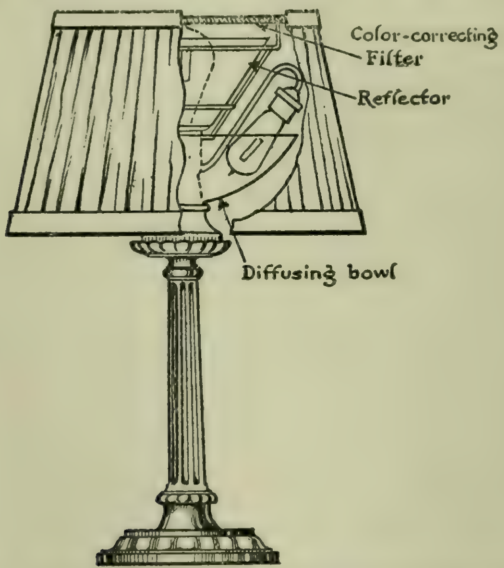

Fig. 2.—A table lamp for a den or for local lighting in a living room.

highest point will form the apex of a right angle with a line drawn from the maximum reading distance which is approximately 3 ft.

The diffusing shade which is made of alabaster acided glass is so designed that its general curvature is somewhat parallel with the filament of the lamp. This is necessary to assure the greatest efficiency of the diffusion as no reading lamp is efficient without such diffusion.

If the light rays are not diffused either by the interposition of the proper kind of glass or by indirect reflection from a

light colored non-glazed or mat surface, specular reflection from the book or paper which one may be reading is bound to cause eyestrain.

Den or Music Room.—Suppose the specifications of a room are 14 ft. long, 12 ft. wide and 9 ft. 6 in. high; medium dark walls and light buff ceiling. A room of this type can be correctly lighted by a table lamp similar to the one described in the lighting of the living room. Fixtures or bracket lamps are not required but the use of wall lamps may enhance the decorative treatment. If used they should be equipped with lamps of very low candlepower, not over 10 watts; and in selecting the light shields, whether of glass, silk or other fabrics, a low translucency is essential. If the room is used as a music room, it is only necessary to increase the size of the illuminant of the indirect portion of the lamp to obtain the proper amount of illumination. If for economical reasons this is not practical, the lighting scheme must be supplemented by a properly designed local light at the piano.

Dining Room.—I approach the problem of what constitutes correct lighting of the dining room with considerable reluctance. I presume that of all the rooms in the house the dining room is lighted by the most diversified methods. There is no question about the flexibility of the lighting arrangements in this room.

Specifications: dimensions, 18 ft. long, 15 ft. wide and 9 ft. 6 in. high. Ivory colored woodwork, medium straw colored walls, and light buff ceiling. Architecturally, such a room may be called colonial. I have mentioned the color scheme to demonstrate the direct relation between the lighter or darker colored walls and ceiling and the light intensity. Dark toned rooms absorb more light and therefore require a higher candlepower in the illuminant.

The placing of the outlets depends upon the system of lighting to be installed.

Decorators and architects have used with success, from the artistic as well as the good lighting standpoint, side brackets around the room, the light source being properly shielded and supplemented by a candelabra on the table. A room of the dimensions given would require at least six two-lamp side brackets having low candlepower lamps of not over 10 watts

each. This would give a fair general illumination without annoying glare, but it would be necessary to have them all lighted or there would be dark corners or spots upsetting the esthetic effect and also spoiling the correct lighting scheme. This arrangement would not be economical in the moderate priced residence here considered.

Another method of lighting a dining room which has been very extensively used is the so-called glass dome fixture. This is a

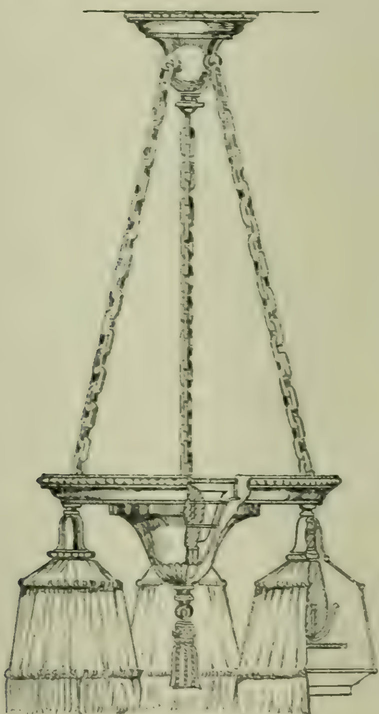

Fig. 3.—A fixture for a dining room.

fixture designed with a large glass dome suspended by a chain or stem over the table. From the decorator's point of view it is particularly bad. It breaks into the symmetry of the room and lacks proportion to its surroundings. It is the most conspicuous object; it occupies a position which compels it to dwarf everything around it; it also prevents the artistic arrangement of floral decorations. From the physiological side the dome light-

ing fixture is far from desirable. The table cloth is so brightly lighted that there is a decided glare. A very simple experiment will demonstrate this point. If the cloth is suddenly removed from the table, the effect will be as if some of the lamps had been extinguished, for the room will seem almost dark. The table cloth has acted as a diffusing medium for the direct light under the dome. If doilies are used instead of the cloth, one is likely to be troubled with specular reflection from the polished surface of the table. It is possible to reduce the extreme brightness upon the table by the use of some diffusing medium such as a silk disk, but even with this precaution, the glare is not entirely eliminated because the source of illumination is so near the surface of the table.

Another objection to the use of the dome fixture is the fact that those seated at the table are constantly looking from a light to a dark zone and vice versa. Each change of the direction of the gaze under such condition causes continual dilation and contraction of the pupil with its consequent visual fatigue. This defect can be overcome of course by the use of side brackets or ceiling fixtures, but the addition would not be economical.

As the specifications of this dining room do not call for a beamed ceiling, one might place the outlet in the center of room and install a semi-indirect or indirect fixture to suit the conditions.

As the ceiling is 9 ft. 6 in. high, and because the light source is placed over the table, it is possible to hang the fixture only 5 ft. 6 in. from the floor. This would leave sufficient distance between the ceiling and the top of the bowl to permit of a wide distribution of the light and eliminate light spots on the ceiling. This overcomes the artistic defects apparent under the other conditions. By the use of an amber colored disk over the bowl of the fixture, the white light from the tungsten lamp may be changed to soft warm tones, which will improve the beauty of the artistic scheme of the room. To eliminate whatever flat effect of diffused lighting may exist, it is only necessary to add outside direct light units arranged around the glass bowl of the semi-indirect fixture or the opaque bowl of the indirect fixture according to the taste of the designer. This addition will correct

the light balance by giving to the surroundings light and shadow. In providing against the physiological defects of such a fixture, thought must be given to the design and color of the glassware or silk. The glass should be properly tinted with a yellow tone and if silk is used amber and champagne colors are preferable. Care must be exercised in lamping the fixture. The outside direct lamp units must not exceed 10 watts while the inside lamps must be larger but not to exceed 60 watts.

By this arrangement the center lamp will give the necessary general illumination and the outside lamps the supplementary. For the sake of economy it is a good plan to have the wiring for two circuits.

In clearing or setting the table it is not essential that all the lamps be lighted. In the design of the silk shade of the lamp which I have shown, considerable compromise has been made. In the purely technical design, the line representing the side of the shade should form a somewhat wider angle so that the side of the shade would be parallel to the line of vision of the average height person sitting at the table, to avoid the possibility of any glare. The flange at the bottom leaving a 4 in. opening prevents a person seated at the table from seeing the lamps and the glare from the reflecting surface.

The lamps within the silk shades are equipped with amber colored disks and as a result a beautiful soft warm light is cast evenly over the table. The opaque bowl contains the indirect lighting equipment over which is placed an amber plate. This type of fixture combines general illumination with the local lighting over the table and at the same time adheres to the important principles of good lighting.

Where service lighting is required, such as in kitchen, pantry and etc., fixtures placed as closely as possible to the ceiling, and therefore above the line of vision, are recommended. The shades, preferably opal glass frosted on the inside and of the distributing type, should be about 7 or 8 in. in diameter and with depth enough to hide the lamp.

In some instances a side wall lamp is required; in that case the bracket should be equipped with a rather dense opal glass, deep enough to cover the whole lamp, the lamp, of course, being placed up or down according to the position of the outlet.

Regarding the proper lighting of a bed room, efficiency and economy are the essential features to be considered. By placing one outlet in the center of the room and one over the dresser, it is possible to obtain good results. A fixture placed close to the ceiling, having a lamp housed in an artistically etched and yellow tinted distributing type of shade, from 7 to 8 in. in diameter with sufficient depth to cover the lamp, is often quite satisfactory. The interior of the shade should have a roughed or mat surface in order to diffuse the light properly. As the fixture is placed well above the line of vision and the distance between the filament of the lamp and glass will be sufficient to eliminate spot glare from the filament, good general illumination without glare and at the lowest cost will be obtained. The fixture can be artistically designed and installed at a very small cost. The dresser light should be suspended over the middle of the mirror and 10 to 12 in. in front. Five feet ten inches from the floor is the average height for a fixture of this type. This, however, is more or less optional according to the conditions. In the main, the specifications of the ceiling fixture will apply in this case, with the exception that the shade, if made of glass, must be so tinted as to prevent glare. This is very important as the shade is directly within the line of vision. A silk shade is preferable to a glass one for this reason, as well as for the better artistic effect. As the light is directly from above, a woman will have no difficulty in arranging her hair according to the latest vogue. The light being well diffused within a considerable range, there should be no difficulty in seeing well.

There are one or two points in regard to bathroom lighting, especially interesting to the man of the house, which it is well to mention. Most bathrooms in moderate priced houses have medicine closets with mirror doors. The men members of the family use this mirror when shaving. A large number of people do not know that in order to see well before a mirror by artificial light the mirror should be in shadow, so that the face will receive the greater flux of light. By having a bracket outlet placed on each side of the medicine closet and approximately 5 ft. 6 in. from the floor, which is the average height of a man's face, the light source will be in a line with the face and the best results from the light will be obtained. The shades should be of some good diffusing

glass about 5 in. in diameter, deep enough to shield the light source, and hemispherical in design. This type of bracket unit may be termed semi-indirect as the larger percentage of the light is reflected to the wall and ceiling and serves for the general lighting of the bathroom.

I have tried in this paper to add the scientific element to that of the esthetic in the lighting of a moderate priced house and to show how one modifies the other. The results illustrate a statement in the beginning of the paper that good home lighting is more or less a compromise.

DISCUSSION.

Mr. A. L. Powell: The statement in the paper that "the illuminating engineer is likely to tip the scales to the side of the scientific" may be entirely correct from the decorator's position; yet those of us worthy of such a title will do our utmost to make the home comfortable while at the same time striving for the proper artistic effect. So, from a humanitarian standpoint, even if we do give more weight to the serviceability of the lighting, we are on the safe side. I believe that the average individual really does not know a great deal about esthetics, but he certainly can tell when his house is agreeable and healthful. All too often are the fixtures artistically correct when viewed by daylight; but at night cannot be so designated. In a broad sense anything artistic is comfortable.

Another statement that I hardly believe justified is, "Instead of the soft yellow light of the carbon one must now contend with the hard cold white light of the tungsten lamp." It is true that the light from a carbon filament is somewhat more yellow than that from a tungsten filament, but it is safe to say that there is as much glare from the carbon lamp as ordinarily installed, as from the latter, and glare is the important factor. For instance, there are millions of carbon lamps in use on multiple arm fixtures only partly surrounded by some sort of a non-diffusing shade, throwing the light directly into one's eyes. In many cases where tungsten lamps are substituted changes are made in the glassware or fixtures, or both; so on an average the tungsten lamp installation is not as much more harsh as might be imagined.

Following this line of reasoning, it is doubtful if a semi-indirect or totally indirect fixture, no matter how improperly applied, will ever "get on one's nerves," as much as the great majority of direct lighting fixtures. While on this subject of comparative value of various illuminants, it seems a rather broad conclusion that the slight difference in color between the carbon and tungsten lamps should be sufficient to cause a person to be depressed or have the blues. One might follow this train of thought and arrive at the conclusion that daylight would be much more likely to cause such an effect than the yellowish artificial light.

To me a room does not necessarily look flat if indirect systems are properly employed, and I am sure many of us have all seen very beautiful rooms with these types of units. It may be true that an indirect fixture with the loose bowl is artistically incorrect, yet in this connection I might mention a little personal experience. While even now I am not an exponent of indirect lighting applied everywhere, sometime ago I was not at all certain as to the relative merits of the three types of fixtures, so I installed in my home all three systems, direct, semi-indirect and totally indirect, and lived under them for over a year. The living room is lighted from a semi-indirect bowl with an amber dipped lamp within. The light is well diffused. The den is lighted by a totally indirect fixture with a tungsten-filament lamp. The chairs and other surroundings in the two rooms are equally comfortable and there is no reason why we should use one room in preference to the other, yet when we sit down to read or stay around for any length of time we almost invariably go under the indirect lighting.

The author at one point in the paper states that too little attention has been paid to the color of the light. I believe that illuminating engineers take full account of this in designing the lighting for a residence and provide tinted lamps or tinted glassware wherever it seems advisable.

I cannot see how ophthalmologists and oculists could agree that amber light is preferable to other colors. If this is true, certainly any of the incandescent artificial light sources would be more generally desirable than daylight. Possibly color of light

and intrinsic brightness have incorrectly been used synonymously. We will all agree that a diffused light is extremely desirable.

Throughout the paper the author recommends amber tinted light for almost every room. This is a matter of personal preference, but it seems to me that it is largely dependent on the finish of the room. For instance, I would question the advisability of using amber tinted shades in bedrooms, save those decorated in color harmonizing with this tint. My experience and observations have indicated that the average bedroom is papered with some sort of light blue or light pink flowered decoration, with possibly a light purple or green, or some other dainty figure. There is glassware available in commercial forms which has, for instance, a light blue medallion on an etched white background, or pink flowers with delicate green leaves on the white glass. One may choose among these glassware to match almost any scheme of room decoration. They are attractive and fit in so well with the room treatment that a most pleasing effect is secured.

I will grant that the dome in the dining room may be incorrect from a decorative standpoint, yet a great many persons with whom I have talked upon this subject favor such an arrangement of light. For the reason that the table is the part of the room where one desires to have attention concentrated. The hygienic objections to a dome are removed by hanging it at the proper height and covering its base with a slightly tinted light diffusing silk screen. The lighting should blend so well with the general purpose of the room that one should not notice of what the lighting consisted.

In the kitchen it does not seem desirable to use reflectors etched on the inner surface, as there is likely to be a certain amount of grease and smoke from the cooking and on such a rough surface this dirt will readily collect, and it is difficult to keep it as clean as necessary. I believe it is preferable to use a rather dense, smooth opalescent reflector or prismatic bowl-shaped reflector. These are particularly efficient and in the kitchen where the lighting is somewhat of a commercial proposition. A high intensity of illumination is desired on the food as it is being prepared, and the light must be obtained in the most

economical manner. It is the one room in the house where economy is the primary factor.

MR. M. LUCKIESH: I believe that if every fixture man would attack the problem of uniting science and art or utility and esthetics as Mr. Cassidy has done, proper lighting would experience the greatest boom in its history. The matter of proper fixture design is one of the most serious problems the lighting specialist has to deal with. I believe Mr. Cassidy has handled this subject well from the standpoint of the fixture man who has naturally been chiefly interested in the esthetics of design. The paper is a valuable one even though we all do not agree with some of the statements. That condition is not unusual, for we do not thoroughly agree on some of the fundamentals of lighting. It is often difficult to unite utility and beauty, but it must be done.

Mr. Powell stated that the average man knows when his home is agreeably lighted. How he has found this out I am at a loss to imagine. In the first place the "average man's" home is not agreeably lighted. Secondly when we consider that the average man does not know when his home is badly lighted (which is unquestionably the case at the present time) it is difficult to see how he would know when his home is agreeably lighted.

Regarding efficiency we must remember that, especially in the home, the real efficiency is a measure of how well the lighting apparatus fulfils its object. And we must remember that its object is not pure utility unless we include the utility of beauty. As Dr. E. P. Hyde expressed in the Johns Hopkins lecture course, "efficiency is the ratio of satisfactoriness to cost and not the reciprocal of cost"

I agree with Mr. Cassidy's statement that color is the keynote in illumination of the home. I seriously doubt that tungsten light "gives one the blues" any more than the carbon lamp especially in view of the fact that we work under daylight with satisfaction many hours each day. However I believe quality of light should be considered a matter of personal taste as long as extremes are not indulged in. Mr. Cassidy uses amber glass very much. He uses it over the "indirect" portion of some of his fixtures. This light reaches the objects in the room after

reflection from the ceiling and walls. The most common trend in the color of walls and ceiling is toward cream, yellow, brown, etc., that is, toward the "warmer" colors. I have shown in a previous paper (TRANS. I. E. S., Feb., 1913) that only an apparently slight tint in wall coverings is sufficient to convert the tungsten light by reflection to a quality even more yellow than that of the carbon lamp light. Amber glass has not appeared satisfactory to me owing to the greenish tinge. I have therefore been experimenting for some time with the hope of producing a proper yellow for converting tungsten light into the quality of the light from a carbon lamp and yet enjoying the efficiency of the former.

I have made many experiments with colored lights in the home. These have ranged from deep amber to the lighter yellows, rose, artificial daylight, etc. While I believe the results are largely a matter of personal taste, I will state as my opinion that an unsaturated yellow color is the most pleasing to me and appeared to be a welcome change from daylight where daylight color-values are not essential.

In the matter of the den mentioned in the paper I would state that I believe it is well to avoid the use of too dark walls so commonly found in dens. I have found by experiment that in reading under a well-designed table lamp and facing a dark wall that I suffered very noticeable eye-fatigue in a short time.

I agree with a previous speaker that the dome is a satisfactory fixture when well designed. However, it is possible to get practically the same lighting effect from showers. Take a shower with deep narrow bell-shaped shades equipped with bowl-frosted tungsten lamps. Direct light is sent downward upon the table and light of any color depending upon the color of the shade is diffused about the room. By this method the table is the brightest object in the room. I believe this should be the case and therefore do not recommend so-called semi-indirect lighting in the dining room. I believe there is nothing more important in promoting sociability than the semi-darkness pressing in on a group surrounding the table.

I am sure that we agree that Mr. Cassidy's paper is very timely. In his last paragraph he sums up the situation very well

in the statement that he has tried in his paper to add the scientific element to that of the esthetic in the lighting of a moderate-priced house and to show how one modifies the other. I think this is highly commendable and suggest that we all must realize that the fixture man can well reciprocate our efforts to enlighten him in bringing home to us an extremely important phase of lighting—the esthetic.

MR. L. C. PORTER: A great many of us are living in homes already equipped with fixtures, which are not so attractive as those shown here. Some very simple changes will frequently make large improvements in many of the fixtures found in moderate-priced houses and apartments. In the kitchen, for example, there is frequently a single one-light fixture in the center of the room. The use of a socket with a separable attaching plug will allow a drop-lamp to be run over to the table or other place where food is prepared; this is a great convenience and will permit the use of an electric flat iron and similar equipment at night.

Many dining rooms are equipped with domes, having bracket arm showers around the center dome. It is a very simple matter to give these brackets a half turn, pointing them towards the ceiling, and install a 10-watt all-frosted tungsten lamp in each bracket. This will produce a low intensity semi-indirect illumination over the entire dining room. If, in addition to this, an efficient reflector equipped with a 60-watt tungsten lamp is fastened in the dome itself, directing a strong intensity of light onto the table top, excellent dining room lighting will result; *i. e.,* low general illumination throughout the entire room with strong light on the table, making the table and those sitting around it most conspicuous in the room.

The question of amber light is probably one of individual taste. Personally, I do not care for it in a dining room, because it causes the linen on the table to appear more or less yellow, giving it a somewhat faded out appearance; whereas a strong white light makes it appear fresh and clean.

In the living room many table lamps at present in use can be improved by the use of lamps which are amber dipped on the upper half, thus giving a pleasing color to the shade itself, and at the same time throwing white light downward for reading.

Fixtures having a sort of hollow brass shell, from which showers are hung, are often found in these rooms. It is a simple matter to place in the top of this brass shell a 100-watt tungsten lamp in an efficient reflector pointed towards the ceiling and connected with a drop-cord to the nearest shower socket. If the bowl of the 100-watt lamp is amber-dipped, semi-indirect lighting will be obtained. Very nearly the same results can be obtained by painting the inside of the brass shell white, instead of placing the reflector there.

It frequently happens that in the bedroom there are candlesticks of one type or another, which it is not difficult to wire and connect by a drop-cord from the top of the bureau to the nearest lamp socket. A little 15-watt all-frosted tungsten candle lamp in these candlesticks, one placed on each side of the mirror, makes a useful ornament for a dresser.

The thought, therefore, which I wish to leave with you is that considerable improvement can be made in the average fixture at very little expense, and that it is good policy for the electric light representative to assist the small purchaser—who does not feel that he can afford the more elaborate fixtures—to make such changes, thereby obtaining the confidence of one who some day may be a large customer.

Mr. G. L. Hunter: During the past few years, this Society has changed its point of view greatly. Several years ago when I read my first paper here, on the subject of "Light and Color in Decoration," many of you thought I wandered far afield because I ventured to take up problems that had not previously been even suggested. I ventured to say even then that white light for residence lighting is not desirable. I ventured to say that there are many different kinds of daylight; that as the environment changes, the daylight changes. Daylight reflected from the sands of the seashore is one thing; from the blue depths of the ocean, another; from green forests and green grass, another; from brown loam, or gray sagebrush, another; from red brick buildings, or white marble buildings, another. As the clouds overhead change, as the color of the skies changes, the color of the daylight changes. The color of the daylight also depends upon the hour of the day. At early dawn when the sun first arises, it is glorious

with red. As the sun ascends through the sky, the color of the light changes from red through golden yellow to pure white at noon.

Naturally, the constant discussion of color here to-night has delighted me, for it was precisely what I had hoped to provoke. I felt that until color was the first subject discussed in residence lighting, and to some extent in all illumination, you were wasting most of your effort; that your ideals as well as your practise were wrong. The discussion here to-night makes it clear that color is now foremost in the minds of those of you who are attempting to improve the lighting of residences.

Mr. Cassidy has certainly presented a very interesting paper. He has not only made many useful suggestions, but has arrived at a number of valuable conclusions. But I did notice one sentence in his paper to which I take the strongest exception. This sentence is "So most homes to-day have lighting fixtures which are esthetically correct." That I emphatically deny. I should say on the contrary that, most homes to-day have lighting fixtures that from the esthetic point of view are abominable. They are ugly in proportion; and incorrect in detail from the point of view of historic style.

Personally I must admit that I am prejudiced in favor of amber light. I know that amber light is softer on the eyes than white light, and that most persons can see better with the light that comes from the middle of the spectrum—I mean with light that is not red and not blue. The effect of amber light can easily be tested by everyone for himself, either under daylight or under artificial light, by looking through a sheet of amber gelatin. Both interiors and exteriors will be made softer and more agreeable to the eye. Many clashes of color that exist in rugs or draperies or wallpapers will be overpowered. Discords that by white light are accentuated will by amber light be eliminated. Even the extreme whiteness of the gas arc light can be agreeably dominated by the use of amber shades. Some years ago I equipped, with amber-and-gold leaded-glass shades, the wall brackets at each end of a room 30 ft. x 16 ft. The shades were sufficiently large so that there was no danger of their being melted apart by the heat, and there was little direct light sent up or down. The

diffusion was largely of amber light in a horizontal direction, or nearly so, illuminating brilliantly the walls of the room from 2 to 8 ft. high. I do not think I ever saw any room more agreeably lighted than this, or less expensively either. There was absolutely no glare, and all the light that reached the eye had been so transformed by the amber and gold opalescent glass of the shades as to be grateful rather than offensive to the eye.

Of course the decorator will always keep in mind, and others always should keep in mind, the fact that light is colored quite as much by reflection as by refraction; that it can be colored not only by the glass bulb of the lamp, and by the glass or paper or silk shade that surrounds it, but also by the walls or furniture that reflect it. The decorator knows that when he colors the walls of a room, he is at the same time coloring the light. If the room is finished in soft tones the reflected light will be soft no matter if it originates from tungsten-filament lamps. If the walls be a muddy white the light will be a muddy light, no matter if it start as a golden yellow.

One thing the decorator will be able to tell the illuminating engineer with regard to amber light, is that it is safer to use, decoratively, than any other light. White light makes a room hard and unsympathetic. Blue light makes the blues of a room cheerful, but makes the reds muddy looking. Red light brings up the reds of a room, but makes the blues sombre and the greens impossible. Amber light alone is sympathetic to all the other colors, eliminating from an interior just enough of the extreme reds and the extreme blues to produce harmony.

Mr. H. Thurston Owens: It is apparent that the ideas which Mr. Hunter brought to the attention of this Society were of great value but the reason they did not receive the attention they deserved was due to the commercial propaganda of considerable influence which was at its height at that time. The commercial propaganda of to-day instead of being at variance with the dictates of art is in accord with them.

Mr. G. H. Stickney: While there are minor points in which my ideas differ from those of the author, I am in agreement with his general thought.

It is not surprising that, on account of our different relations

to the problem and our different antecedents we should have different ideas and should each hold our individual ideas as superior to those of others. So long as there are so many installations which are neither artistic, comfortable nor economical, there is certainly much to be accomplished, and I believe the discussion of a paper such as this helps toward the end of bettering the practise.

The architect, decorator and fixture man handle the problem of home lighting in advance. The central station and lamp manufacturer often attain their closest relation after the installation is in operation, and frequently encounter dissatisfaction, due to appearance, glare, and most often cost of operation. In seeking to secure the best results we meet limitations due to the location of outlets and style of fixtures and glassware. We are inclined at times to blame the designers, though we realize that in many cases they have been unable to express their own ideas on account of the limitations of cost and taste imposed by the client. We do feel that in many cases adherence to historical precedents has prevented designers from adapting their practise to the modern illuminants and other practical modern conditions.

Sometimes in the past we have undoubtedly erred toward the other extreme of placing too much weight on economy of operation or efficiency, as measured in candlepower or foot-candles. On the other hand, I believe that the illuminating engineers, including those employed by the lighting companies and lamp manufacturers, have done more to prevent this class of mistakes than almost any other influence.

A progressive manufacturer is anxious to insure the best possible service from his apparatus, and likewise, the central station is desirous of securing the most satisfactory use of current. They have, therefore, employed illuminating engineers to make a special study of lighting problems to educate and advise light users and those interested in the design of lighting installations. I believe this has done much to prevent undesirable extremes. Much that the artistic designer blames the illuminating engineer for is really done by untrained light users and others, without the advice of the illuminating engineer, in seeking to better unsatisfactory conditions. In such a case it frequently happens that

the light user turns to the opposite extreme, and I have always felt that this result was somewhat the fault of the artist.

Perhaps I can illustrate my thought better by reference to a typical experience in connection with the lighting of a fine hotel in a western city. I was called in because the consumption of energy required by the architect's plan seemed excessive. I found that he was using a considerable number of beautiful fixtures, employing numerous round bulb, frosted carbon incandescent lamps of low power. The effect and design was unquestionably attractive, although it seemed to be unnecessarily extravagant. I had the opportunity of calling the architect's attention to a similar installation he had designed. Although this had been in service less than a year the management had substituted higher power, bare tungsten filament lamps in pear-shaped bulbs, for the round bulb lamps which had been prescribed. As can be imagined the effect was both inartistic and glaring. After the architect had failed to persuade the management to return to the original lighting, it was not difficult to convince him to abandon this type of fixture and design one for the new installation which would be both artistic and effective with clear tungsten filament lamps. Through his ingenuity he discovered that it was possible to make such fixtures which satisfied his artistic ideas even with due regard to precedent; and he himself was protected, as far as his reputation was concerned, from having his artistic work spoiled by those responsible for its operation.

While, technically, architects or fixture designers may not be responsible for the liberties which may be taken with the fixtures which they design, the fact remains that the public does blame them, and it seems to me there is some justice in this wherever it is possible for them to avoid the condition likely to produce these results.

Going back to the cost question: I agree that the home is one of the last places where cost of lighting should be the deciding consideration. It does not seem, however, practicable to entirely ignore this factor; in fact, it sometimes seems to me that the lighting in the fine mansion of the wealthy man is even more liable to be marred in search of economy than in the middle-class

home. I have in mind a number of specific instances of this sort which have come to my personal attention.

It is for the best interest of all of us that we should learn to respect the truth in each other's view points.

Mr. G. W. Cassidy (In reply): Referring to Mr. Powell's discussion of my statement, "Instead of the soft yellow light of the carbon lamp, one must now content with the hard, cold, white light of the tungsten lamp," I wish to say that I referred to the color of the light and not to its physiological effects or glare. Regarding the statement, "Too little attention has been paid to the color of the light," Mr. Powell adds that this condition is being remedied by the illuminating engineer. No doubt this is true of the few cases where the lighting expert is engaged to design the installations of moderate-priced residences.

I have used an amber color in fixtures to bring out the decorative effect of a room, and because it is a more or less neutral tone.

Mr. Hunter takes exceptions to my statement, "Most homes to-day have lighting fixtures which are esthetically correct." I meant that most of the fixtures for residences have been designed simply from the artistic side without regard to the scientific. I agree with him that many of the results in evidence to-day could hardly be called esthetic.

AN ANALYSIS OF REQUIREMENTS FOR MODERN STREET CAR LIGHTING.*

BY L. C. DOANE.

Synopsis: In outlining the requirements of modern street car lighting, the author discusses elimination of eyestrain, maintenance, effect of dust on efficiency of reflectors, efficiency of various lighting units, spacing of outlets, wiring, etc. Tables giving cost and lighting data are appended to the paper.

INTRODUCTION.

The first paragraph in the "Code of Principles" adopted by the American Electric Railway Association at Atlantic City, October 14, 1914, reads as follows:

> The first obligation of a public utilities engaged in transportation is service to the public. The first essential of service is safety. Quality of service must primarily depend upon the money received in fares. For this reason, it is necessary that the rate of fare should be sufficient to permit the companies to meet the reasonable demands of patrons and to yield a fair return on a fair capitalization.

This sums up very concisely the attitude of the public utilities towards service rendered the public. They wish to give every service possible, consistent with economical operation, but they must be sure that any new demands of their patrons are reasonable and that a fair return on their investment is forthcoming.

When it is known that 224,000,000 passengers were carried in Pittsburgh last year in electric street cars; over 1,500,000,000 passengers in New York; and over 500,000,000 passengers in Philadelphia; and more than 40 per cent. of this travel was during hours of darkness, artificial lighting stands out as a basic service that must be rendered by the public utilities. The extent to which this artificial lighting fulfills its duty is the determining factor in regard to the quality of the service.

* A paper read at a meeting of the Pittsburgh Section of the Illuminating Engineering Society, November 20, 1914.

It is the object of this paper to determine what constitutes good lighting and to show that good lighting is an asset to the public utilities from the standpoint of returns on the investment and service to the public.

GENERAL.

The artificial lighting of street cars, in order to be satisfactory, must be acceptable both to the public and the public utilities. An analysis of the requirements to be met, from the standpoint of each interest, shows approximately the following results—assuming that the illuminating engineer is the representative of the public.

REQUIREMENTS.

Public Utilities: 1. Economy of operation; 2. Economy of installation; 3. Safety for passengers; 4. Ease of handling passengers; 5. Advertising value.

Public: 1. Sufficient light; 2. Elimination of eyestrain; 3. Pleasing appearance.

Economy of Operation: Economy of operation depends on the following items: (a) Cost of maintenance; (b) Cost of power; (c) Efficiency of lighting units.

Each of these items will be discussed separately later in the paper.

Economy of Installation.—The following items determine the economy of installation of a lighting system: (a) Wiring; (b) Spacing of outlets; (c) Cost of lighting units. Each of these items will be discussed separately later on.

Safety for passengers; Ease of handling passengers; Advertising value.—Each of these requirements will be met to the fullest extent only when the following conditions are fulfilled: (a) Sufficient light; (b) Elimination of eyestrain; (c) Pleasing appearance.

Sufficient Light: An illumination of 1.5 foot-candles is the minimum intensity consistent with acceptable lighting.[1] Figuring

[1] Ferree and Rand: Efficiency of the Eye Under Different Systems of Illumination; Postoffice Department Specifications for the Construction of Full Postal Cars; A. R. E. E. Report on Day Coach Lighting Tests.

on the basis that the voltage of the lamps often drops to 85 per cent. of normal, which is equivalent to 55 per cent. of normal light, and that a drop in efficiency due to dust on the lighting units will easily amount to 15 per cent., the lighting system should be designed to produce an average illumination of at least 3.75 foot-candles at normal voltage at the plane of illumination. The plane of illumination is usually taken 34 in. (86.36 cm.) above the floor, the elevation at which the average reader holds a paper.

Elimination of Eyestrain: Eyestrain may be caused by insufficient light, heavy shadows, uneven illumination, points of high intrinsic brilliancy in the field of vision, or marked contrasts in illumination to which the eye must adapt itself.

To eliminate eyestrain, it is necessary to remove the causes of eyestrain. The chief causes of strain are, bare lamps with filaments of high intrinsic brilliancy placed in the field of vision, insufficient light, and extreme contrasts.

No lamps should be used except with some form of shield which will cover the bright light source to such an extent as to entirely cut off the view of the brilliant filament from the ordinary field of vision. This shield may be either in the form of a reflector or an indirect bowl.

An indirect lighting system in a street car is so expensive to operate that it will not be considered further in this paper. Experience has proven it an unwise method to adopt at the present time in spite of its merit in reducing eyestrain and eye fatigue.

A reflector, in order to be satisfactory as a shield, must extend well down over the lamp. The approximate screening angle required has been determined by a series of tests conducted by Mr. A. J. Sweet. These tests were conducted to determine the variation of eye efficiency with angle of light entering the eye, and were made by directing a beam of light into the eye and making a determination of what the eye could see under this condition. The first determination was made with the beam directly in line with the eye and then successive determinations were made while the angle at which the light entered the eye was gradually changed. It was found that the eye reached its normal efficiency when the beam of light entered at angles greater than 20

to 24 deg. from the direct line of sight. A graphical summary of the test results is shown in Fig. 1.

It is interesting to know that Mr. Sweet has just completed an exhaustive test for the Wisconsin Commission along similar lines

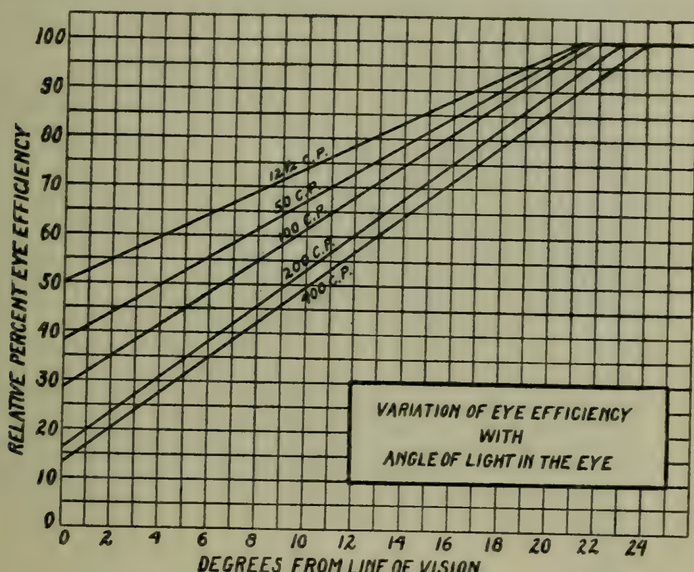

Fig. 1.—Variation of eye efficiency with angle of light in the eye.

to his previous tests and that his original results have been corroborated.

Two striking examples of the importance attached to the angle of cut-off of a reflector are the specifying by the Post Office

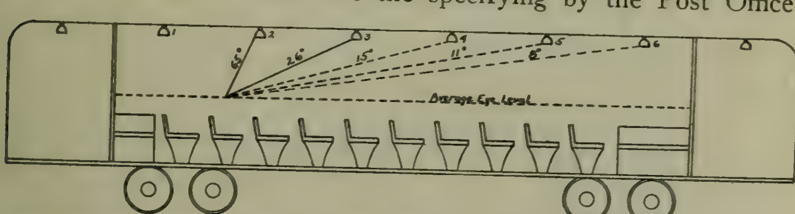

Fig. 2.—Diagram showing angles at which light from different units enters the eyes of passengers. (Light at an angle of less than 20° is that which produces glare and eye fatigue.)

Department of an angle of cut-off of not less than 20 deg. from the horizontal on reflectors used for postal car lighting; and the standard specification adopted recently by the Association of

Railway Electrical Engineers, calling for an angle of cut-off not less than 25 deg. from the horizontal on all reflectors for car lighting.

Fig. 2 shows the angles at which a passenger may receive light from the lighting units in a car. In the case shown by this figure, unit No. 6 has the most injurious effect. Units Nos. 4 and 5 a lesser effect and units Nos. 2 and 3 practically no effect. With bare lamps light enters the eye from each of these units, but by the use of proper reflectors, it is possible to cut off the light from all the units which are so located as to have a harmful effect.

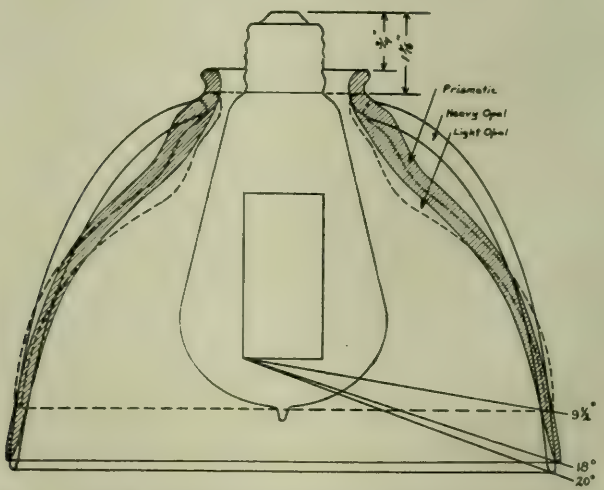

Fig. 3.—Angle of cut-off 56-watt lamp with prismatic reflector, heavy opal reflector, and light opal reflector.

Fig. 3 shows how it is possible to cut off the light above certain angles. The reflectors designated as prismatic and heavy opal have angles of cut-off of 18 deg. and 20 deg. respectively. These two reflectors cut off practically all the harmful light. It might be well to have a slightly greater cut-off, but this could only be obtained at a considerable sacrifice in efficiency. The reflector designated as light density opal does not give a sufficient angle of cut-off and should be changed in this respect before it will fully perform its duty.

Extremes of contrast in intensities may, to a great extent, be avoided by the proper distribution of light upon the plane of

Fig. 4. Center deck car lighting with heavy density opal reflectors.

Fig. 5.—Half deck lighting with medium density opal reflectors.

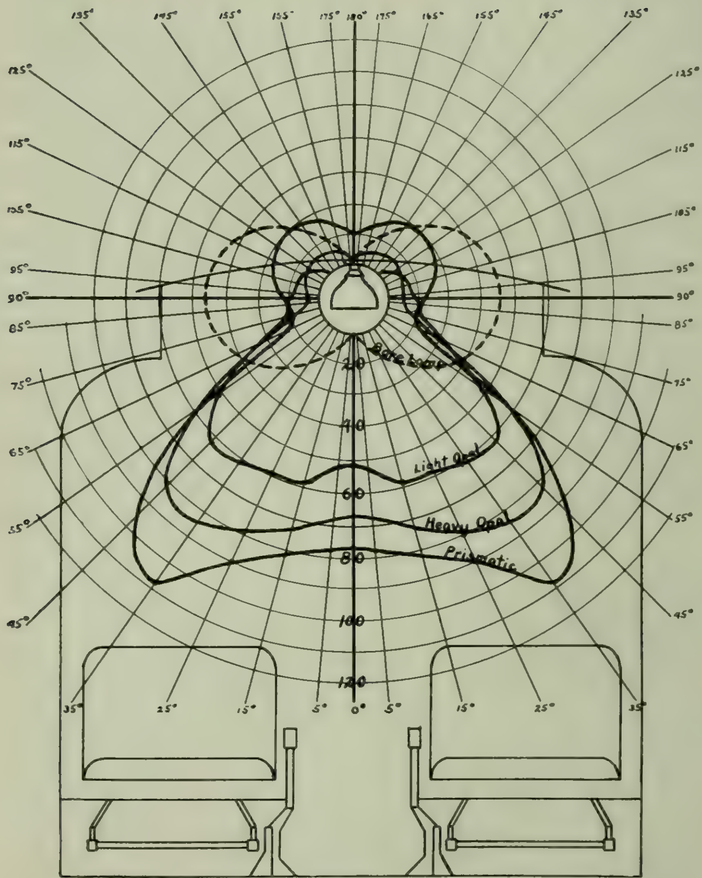

Fig. 8.—Distribution of light from a 56-watt lamp with prismatic reflector, heavy opal reflector, light opal reflector.

illumination and by using a light colored finish on the interior of the car. The interior finish should be unglazed, for a glazed surface would give unpleasant specular reflection.

Appearance: The appearance of a lighting installation governs to a considerable extent its success. An installation that is unsightly or depressing is never a good one, be the engineering results what they may. Opaque reflectors produce a depressing effect due to the gloomy appearance of the upper part of the car in comparison with the lower part. This fact eliminates them from consideration.

The unsightliness of an installation depends to a certain extent, on personal preference. Certain translucent reflectors may be very pleasing to some people while to others they may be rather unpleasant. This condition cannot be avoided. It is safe to say that any translucent reflector—with the exception of a few which, by selective absorption of the transmitted light appear unpleasant in color—will be about equally acceptable to the average public.

Figs. 4 and 5 show two car lighting installations that are in service.

Cost of Maintenance.—The cost of maintenance of an installation is a question of great interest to the public utilities. Here is an expense that starts immediately upon placing a car in service and continues during the life of the car. It is of vital importance that this cost be kept as low as possible, if the greatest returns on the investment are to be obtained.

Maintenance of any magnitude comes down to two items, these being lamp replacements and reflector cleaning.

The life of all lamps is practically the same. The question of the proper lamp for economical maintenance, therefore, comes down to the question of cost of lamps and number of lamps.

Only tungsten lamps will be considered, as carbon and Gem lamps are uneconomical in other respects than that of maintenance. (See discussion under *Efficiency of Lighting Units.*)

The 23-watt and 36-watt tungsten lamps cost exactly the same, say three units. The 56-watt lamp costs four units and the 94-watt lamp costs 7 units. It requires 7.3 units worth of 23-watt lamps, 4.7 units worth of 36-watt lamps and 4.2 units

worth of 94-watt lamps for the same amount of light as is given by 4 units worth of 56-watt lamps. This means that for equal light, maintenance considerations point to the 56-watt lamp as the most economical, the 23-watt lamp being 82 per cent. more expensive, the 36-watt lamp 17 per cent. more expensive and the 94-watt lamp 5 per cent. more expensive.

The cost of cleaning reflectors depends upon the number of reflectors and the length of time before the reflector requires cleaning.

The number of reflectors depends on the size of lamp and the efficiency of the reflector. A full discussion of these 2 points

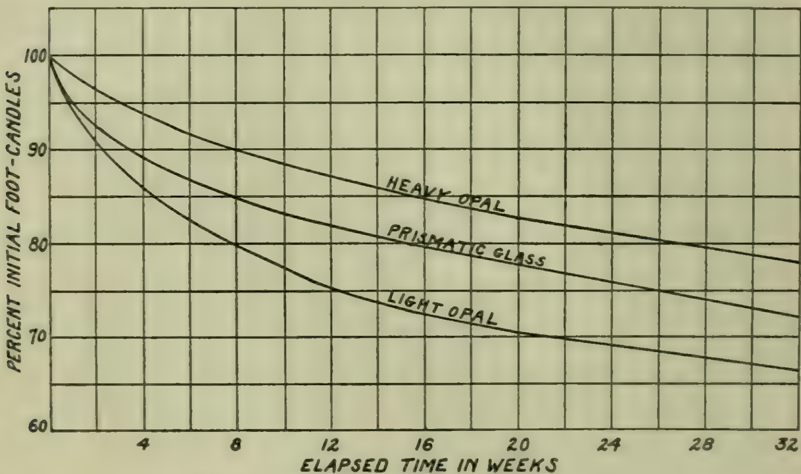

Fig. 9.—Effect of dust on efficiency of reflectors.

is given under the headings of *Spacing of Outlets* and *Efficiency of Lighting Units.*

The length of time before the reflector requires cleaning depends on the rapidity with which efficiency drops off due to accumulation of dust, and to appearance.

Fig. 9 shows graphically the effect of dust on the efficiency of three types of reflectors. This test was made by the engineering department of the National Lamp Works to determine the relative merits of reflectors for factory service, but the results are equally applicable to car lighting if only relative values are used. From this figure, it is seen that the efficiency of heavy density

opal reflectors is least affected by dust accumulation. Prismatic reflectors come next and light density opal reflectors last.

Cost of Power.—Electric power costs the public utilities money, whether it be bought or generated in their own plants. Every additional kilowatt of energy used means an additional investment in generating units, distribution and feeder lines, and in sub-station equipment. Public utilities are constantly expanding adding more cars, extending their lines, requiring more power. The argument that an economy of power is not a real economy seems hardly justified under these circumstances. The day of the public service commission and the elimination of all needless expense is here, and it is such items as economy of power that are going to lead to the highest economic efficiency. A study of the discussion on *Costs* will throw some interesting light on this subject.

Efficiency of Lighting Units.—Under the heading *Sufficient Light* it has already been stated that there is a minimum intensity for satisfactory lighting. It is also true that the most efficient method of obtaining this intensity will require the least amount of energy.

Table I shows the average efficiency of various lighting units as obtained by a series of tests which is described later under the heading *Tests.*

TABLE I.—Efficiency of Various Lighting Units.

Lighting unit	Efficiency Per cent.	K
Bare carbon lamp	8	0.6
Bare tungsten lamp	22	1.6
Light density opal reflector	35	3.0
Medium density opal reflector	40	3.5
Heavy density opal reflector	45	4.0
Clear prismatic reflector	54	4.6

The reason for the increase in efficiency with the use of tungsten lamps and reflectors is first, that the tungsten lamp generates light practically 3 times as efficiently as does the carbon lamp and second, that reflectors will so redirect the light of the tungsten lamp as to make much more of it useful in lighting the bottom of the car instead of the top. Fig. 8 illustrates very effectively the way in which the light of the bare tungsten lamp is redirected down onto the seats by various reflectors.

Wiring.—There are four methods of wiring which are in general use for car lighting. These are as follows: 1. Exposed wiring between roof and headlining; 2. Conduit wiring between roof and headlining; 3. Open conduit wiring on ceiling; 4. Open conduit wiring on roof.

The first two methods are probably best for wiring new cars or wiring old cars while they are shopped for general overhauling. The latter two methods are the most economical for changing over an old car, and are necessary when there is a very small clearance between the headlining and roof.

Local conditions will have to determine which method of wiring is most economical, until such time as street car designs are standardized.

Spacing of Outlets.—Spacing of outlets depends on the efficiency of the lighting unit, the distribution of light by the lighting unit, and the seating arrangement of the car.

The Association of Railway Electrical Engineers in its report on "Day Coach Lighting Tests" finds that a spacing of 6 ft. to 7 ft. 6 in. (1.82 to 2.28 m.) between units should not be exceeded, as greater spacing produces uneven lighting and objectionable shadows. They also found that there was no advantage to be gained by using two rows of lighting units instead of one, but this may be modified in street car lighting practise. It is quite probable that two rows of units reduce shadows in street cars having longitudinal seats, although the increased cost of installation and maintenance for such a system is very likely to offset any gain in illumination that may be made.

By calculations from the results of the tests on the efficiency of various lighting units, it is possible to determine the maximum allowable spacing for any units. The results of these calculations are given in Tables II and III.

TABLE II.—Maximum Allowable Spacing of Units.
Half-Deck System. Two Rows of Units.

	Size of lamp			
Reflector	23-w	36-w	56-w	94-w
None	2 ft. 6 in.	4 ft. 3 in.	6 ft. 0 in.	——
Light density opal	4 ft. 9 in.	——	——	——
Medium density opal	5 ft. 9 in.	——	——	——
Heavy density opal	6 ft. 6 in.	——	——	——
Prismatic clear	7 ft. 0 in.	——	——	——

TABLE III.—MAXIMUM ALLOWABLE SPACING OF UNITS.

Center-Deck System. One Row of Units.

Reflector	Size of lamp 23-w	36-w	56-w	94-w
None	1 ft. 3 in.	2 ft. 0 in.	3 ft. 0 in.	5 ft. 6 in.
Light density opal	2 ft. 6 in.	3 ft. 9 in.	5 ft. 9 in.	7 ft. 6 in.
Medium density opal	2 ft. 9 in.	4 ft. 6 in.	6 ft. 6 in.	——
Heavy density opal	3 ft. 3 in.	5 ft. 0 in.	7 ft. 0 in.	——
Prismatic clear	3 ft. 9 in.	5 ft. 9 in.	7 ft. 6 in.	——

Cost of Lighting Units.—The cost of lighting units depends upon the cost of holders, lamps and reflectors.

Holders for the various sizes of lamps are all the same and therefore the fewer the units required, the lower is the cost for holders.

It has already been shown that for equal amount of light the 56-watt lamp is most economical.

Reflectors vary in cost according to the glass that goes into them and the cost of the molds in which they are made. It is a peculiar fact that the lower the efficiency of a reflector the lower is its cost. An investigation of the discussion on *Costs* will, however, show that though the individual reflectors may vary in cost, the increased efficiency of the more expensive ones permits the use of a fewer number, which brings them all down to practically the same plan.

The selection of lighting units, therefore, should be made on the basis of maintenance cost and economy of operation, rather than on the cost of the lighting unit itself.

Tests.—A majority of the various comparative tests conducted to determine the efficiency of an installation, have been made on only two or three types of reflectors and these often the wrong size or type for the service. It has also been the practise to use uncalibrated lamps, inaccurately calibrated instruments and fluctuating voltage. Under such circumstances the probability of rather serious errors is introduced.

During the last part of May, 1914, an illumination test embodying twelve different installations was made on one of the double-truck closed cars operated by the Indianapolis Traction & Terminal Company. Every precaution was taken to make the re-

sults accurate and conclusive. The car in question measured 7 ft. 6 in. (2.28 m.) wide by 32 ft. 6 in. (9.9 m.) long inside.

Photometric readings were taken on a test plane 34 in. (86.3 cm.) from the floor, at twenty stations 30 in. (76.2 cm.) apart, each on one of three position lines, one intersecting the position

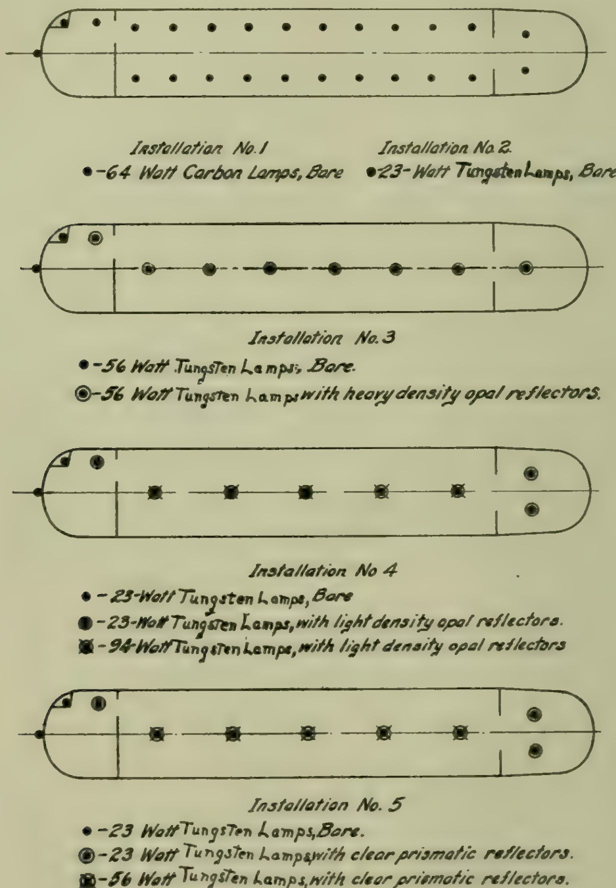

Fig. 11.—Arrangement of lighting units.

of passengers seated next to side windows, another intersecting the position of passengers seated next to the aisle, the third coincident with the longitudinal center line of car.

All instruments were calibrated in the laboratories of the National Lamp Works immediately prior to the tests. All lamps

were rated—with the exception of the 64-watt carbon lamps and 23-watt tungsten lamps—and the exact amount of light obtained from each of them was known. All voltages were held constant by means of rheostats and greatest accuracy was used in making the readings. At the end of every third or fourth test, a check reading was made on the bare lamps to see that no changes had occurred either in the output of the lamps or in the reading of the instruments.

Table IV gives a summary of the results of these tests, and lists all items of importance.

COSTS.

In order to form an idea of the comparative costs of lighting with various installations, the figures shown in Tables V, VI and VII have been prepared.

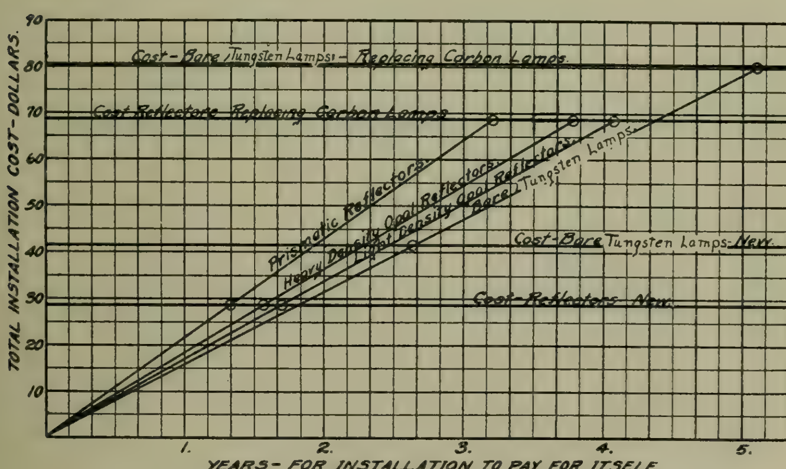

Fig. 12.—Length of time required for installations to pay for themselves.

Five typical installations have been figured.

Fig. 11 shows the arrangement of the five installations.

Table V shows the cost of power and maintenance.

Table VI shows the investment.

Table VII compares the various installations with respect to cost of power and maintenance, and amount of investment.

Fig. 12 shows in graphical form the length of time required for each installation to pay for itself, both when replacing carbon

lamps that have already been installed and when making an installation in new cars.

CONCLUSIONS.

The intention of this paper is to present what data there is available on street car lighting and allied subjects before you in such form that each one may draw his own conclusions.

APPENDIX.

TABLE IV.—CAR LIGHTING TESTS CONDUCTED BY INDIANAPOLIS TRACTION AND TERMINAL CO., INDIANAPOLIS, IND., MAY, 1914.

Test No.	Number lamps	Type lamp	Type reflector	Total watts	Average illumination (foot-candles)	Per cent. effective lumens	Average per cent. variation from average	Foot-candles per watt per sq. ft.
1	17	64-w. carbon	None	1,088	2.62	23.3	12.6	0.58
2	17	23-w. tungsten	None	391	2.60	21.7	11.1	1.63
3	10	56-w. tungsten	None	560	4.94	25.5	10.1	2.16
4	10	56-w. tungsten	Prismatic	560	8.94	46.1	11.4	3.91
5	10	56-w. tungsten	Light opal (Alba)	560	7.08	36.5	9.4	3.10
6	10	56-w. tungsten	Light opal (Druid)	560	6.24	32.4	13.0	2.73
8	5	94-w. tungsten	None	470	3.72	22.5	10.3	1.94
9	5	94-w. tungsten	Prismatic	470	8.84	53.5	19.4	4.61
10	5	94-w. tungsten	Medium opal (blown Sudan)	470	6.64	40.2	17.6	3.46
11	5	94-w. tungsten	Light opal (Alba)	470	6.26	37.9	18.3	3.26
13	5	94-w. tungsten	Light opal (Druid)	470	5.27	31.9	13.4	2.75
14	5	94-w. tungsten	Heavy opal (Mazdalite)	470	8.57	51.9	20.0	4.47
17	5	94-w. tungsten	Heavy opal (pressed Sudan)	470	7.21	43.6	17.0	3.76

Car—Double truck, closed car, 7 ft. 6 in. (2.28 m.) wide by 32 ft. 6 in. (9.9 m.) long inside.
Test plane—Horizontal, 34 in. (86.3 cm.) above floor.

TABLE V.—COST OF POWER AND MAINTENANCE.

	Installation									
	No. 1	No. 2	No. 3		No. 4			No. 5		
	64-w. carbon bare	23-w. tungsten bare	56-w. tungsten H. opal	56-w. tungsten bare	94-w. tungsten L. opal	23-w. tungsten L. opal	23-w. tungsten bare	56-w. tungsten prism	23-w. tungsten prism	23-w. tungsten bare
Number units in car	25	25	8	2	5	3	2	5	3	2
Total watts	1,600	575	448	112	470	69	46	280	69	46
Hours lighted per year	1,707	1,707	1,707	1,707	1,707	1,707	1,707	1,707	1,707	1,707
Kilowatt-hours per year	2,731	982	765	191	810	118	78	478	118	78
Cost per kilowatt-hour	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cost—energy per year	$27.31	$9.82	$7.65	$1.91	$8.10	$1.18	$0.78	$4.78	$1.18	$0.78
Lamp hours per year	42,700	42,700	13,700	3,400	8,500	5,100	3,400	8,500	5,100	3,400
Life of lamps, hours	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500
Lamp renewals per year	28.5	28.5	9.1	2.3	5.7	3.4	2.3	5.7	3.4	2.3
Net cost lamps ($5,000 contract)	0.146	0.207	0.276	0.276	0.483	0.207	0.207	0.276	0.207	0.207
Cost—lamps per year	$4.16	$5.90	$2.51	$0.64	$2.75	$0.70	$0.48	$1.57	$0.70	$0.48
Cost of labor—lamp renewals (assume 2 cents per lamp)	$0.57	$0.57	$0.18	$0.05	$0.11	$0.07	$0.04	$0.11	$0.07	$0.04
Cost of labor—reflector cleaning (3 cents per reflector every 3 months)	none	none	$0.96	none	$0.60	$0.36	none	$0.60	$0.36	none
Total cost—power and maintenance	$32.04	$16.29	$13.90			$15.17			$10.67	

TABLE VI.—INVESTMENT.

	Installation									
	No. 1	No. 2	No. 3		No. 4			No. 5		
	64-w-carbon bare	23-w. tungsten bare	56-w. tungsten H. opal	56-w. tungsten bare	94-w. tungsten L. opal	23-w. tungsten L. opal	23-w. tungstsn bare	56-w. tungsten prism.	23-w. tungsten prism.	23-w. tungsten bare
Total number lamps per car	25	25	8	2	5	3	2	5	3	.2
Net cost lamps on $5,000 contract	0.146	0.207	0.276	0.276	0.483	0.207	0.207	0.276	0.207	0.207
Total cost of lamps	$3.65	$5.17	$2.21	$0.55	$2.41	$0.62	$0.41	$1.38	$0.62	$0.41
Number reflectors per car	none	none	8	none	5	3	none	5	3	none
Net cost of reflectors	none	none	0.48	none	0.532	0.262	none	0.534	0.496	none
Total cost reflectors	none	none	$3.84	none	$2.66	$0.79	none	$2.67	$1.49	none
Number holders per car	25	25	8	2	5	3	2	5	3	2
Net cost of holders	0.20	0.20	1.15	0.20	1.15	1.15	0.20	1.15	1.15	0.20
Total cost holders	$5.00	$5.00	$9.20	$0.40	$5.75	$3.45	$0.40	$5.75	$3.45	$0.40
Wiring, labor and other items (assume $1.25 on outlet)	$31.25	$31.25	$10.00	$2.50	$6.25	$3.75	$2.50	$6.25	$3.75	$2.50
Total investment	$39.90	$41.42	$28.70			$28.99			$28.67	

TABLE VII.—RECAPITULATION.

	Installation				
	No. 1 25 64-w. bare carbon lamps	No. 2 25 23-w. bare tungsten lamps	No. 3 13 36-w. H. opal 2 36-w. bare	No. 4 5 94-w. L. opal 3 23-w. L. opal 2 23-w. bare	No. 5 5 56-w. prism. 3 23-w. prism. 2 23-w. bare
Grand total investment	$39.90	$41.42	$28.70	$28.99	$28.67
Additional investment for improved system	—	$ 1.52	—	—	—
Saving in investment by improved system	—	—	$11.20	$10.91	$11.23
Grand total cost per year	$32.04	$16.29	$13.90	$15.17	$10.67
Saving in cost per year over bare carbon lamps	—	$15.75	$18.14	$16.87	$21.37
Saving in cost per year over bare tungsten lamps	—	—	$ 2.39	$ 1.12	$ 5.62
Interest on investment by replacing bare carbon lamps	—	38%	63%	58%	75%
Interest on investment by replacing bare tungsten lamps	—	—	8.3%	3.9%	19.6%
Saving in investment on new installations over bare carbon lamps	—	4% higher	28%	27%	28%
Saving in investment on new installations over bare tungsten lamps	—	—	31%	30%	31%
Saving in car miles per year by replacing carbon lamps (average earning per car mile—26 cents)	—	61	70	65	82

DISCUSSION.

MR. S. G. HIBBEN: The fittings used here were developed specially for this high voltage service. The voltage across the base terminals of a lamp, in case of a burn-out or an open circuit, would be momentarily the full line voltage of 1,200; therefore, the space separating the contact points was increased from $^{3}/_{16}$ to about $^{3}/_{8}$ in., or in other words a mogul base was necessary, instead of the standard Edison base, to safe-guard against arcing over. This large base in turn necessitated a special shape of lamp bulb and the use of a shade with a fitter larger than the standard 2¼ in. size. A metal holder is manufactured to properly cover the outlet box (all the wiring on high-voltage circuits should preferably be in metal conduit) and this holder takes a white glass shade with a 3¼ in. fitter.

Sometime ago it was debated whether, on account of possible breakage due to inertia of the shade and sudden stopping and starting of cars, it would not be better to standardize a 2¾ in. or a 3¼ in. fitter for the usual installation. However, the results so far have indicated that no trouble is to be found when using a shade with the regular 2¼ in. fitter. Of course, it is assumed that this refers to only those properly made shades which are carefully annealed.

There is on the market a metal holder for shades with 2¾ in fitters, for which prismatic or white glass shades are available. either with or without a lip.

If any operating companies find that they lose a considerable number of lamps by theft, they may prevent this through the use of a lamp receptacle in which the lamp screws into a closely coiled spring wire. This wire acts as a screw thread, allowing the lamp base to be inserted easily, but fastens it when one attempts to unscrew the lamp. Pressing out the coiled wire by a screw-driver blade or similar tool allows the lamp to be removed.

The author presents exact data on the angles at which glare is found, but shows results of some experimentations that is difficult to perform, and rather uncertain to generalize upon. As to angles of cut-off in shades of various depths, it is a matter of considerable difference of opinion as to how deep a shade must be. Other tests might lead to different results.

Obviously, also, any shade through which the light is not softened will not be satisfactory, whatever its depth and its large angle of cut-off.

Judging from observation of open-bottom shades of various depths, I would always advocate using bowl-frosted lamps with 94-watt units, and in some cases on other sizes as well.

Fig. 7 gives interesting data, but would be more nearly applicable to car lighting if one could know what were the conditions of test. The shapes of reflectors, the surroundings and other items all enter into and influence such results.

The cleaning cost for any shade installation, I believe, will usually be found to be greater than that given in Table V, at least in Pittsburgh.

Mr. G. W. Roosa: Reflectors should be cleaned as often as the car windows; but I imagine that in general practise this is not done since dirt on shades and lamps is not so apparent. Many operators do not realize the amount of the loss of light due to dirt.

PHYSICAL PHOTOMETRY.*

BY HERBERT E. IVES.

Synopsis: This paper deals with the question of substituting some physical instrument for the eye in photometry. The nature of light as a measurable physical quantity, the defects of the eye as a measuring instrument and the desirable qualities of a physical photometer are reviewed. Next the various means which have been suggested are examined, among these selenium, the photo-electric cell and the photographic plate. A new thermo-couple artificial eye is described, with an account of its performance as a laboratory normal eye for colored light photometry.

INTRODUCTION.

It is perhaps not unsafe to say that the great majority of those who have photometric observations to make in the course of their daily work have at one time or another been attracted, or even fascinated, by the idea of finding some substitute for the eye, some instrument to make light measurement more like other kinds of measurement to which we are accustomed. Whether the object sought is greater sensibility, simplification of apparatus, greater ease in reading, or the production of an artificial normal eye to help solve the heterochromatic photometry difficulty, the panacea recurrently brought forward is the physical photometer.

As is usually the case when the same idea arises spontaneously in many minds, there is a real field—or rather fields—for devices to take the place of the eye. But, as is frequently the case with a popular idea, there have been many premature and ill-considered attempts to use this or that medium sensitive to light, attempts based on insufficient or faulty analysis of the real requirements. Much misdirected work might have been saved or made useful had it been preceded by a very careful study of the real weaknesses of visual photometry.

The present paper is an attempt at a thorough analysis of the light measurement problem from the standpoint of a possible purely objective means of solution. This analysis must start at the basis of photometric science with the query: What is light? It must then study the eye as a measuring instrument; it must establish criteria to which an artificial eye must conform. Fol-

* A paper read at a meeting of the Philadelphia Section of the Illuminating Engineering Society, November 7, 1914.

lowing this, a review will be made of the various promising instruments and methods for physical photometry, noting how closely they approach the criteria established. From this study it is hoped to show what forms of physical photometers are even now available for some kinds of work, and what we may look forward to in the near future.

WHAT IS LIGHT?

Steering clear of what has appeared to be a stumbling block to some, let us at once clearly distinguish between the *sensation* of light, which is purely subjective, and the usual cause of that sensation, namely, radiant energy of certain qualities. It is with this latter alone that we have to do at the present time in photometry. Starting then, without further discussion, with the fact that light is to be identified with radiant energy, the most important question demanding answer is how to differentiate light from other forms of radiant energy. The physicist has usually been content to accept Lord Kelvin's dictum that "if you can see it, it is light." Such a conception of the nature of light, perhaps more than anything else, is responsible for the encumbering of our physical journals and texts with values of so-called "luminous efficiencies," which indicate only in the crudest approximation the relative light-giving efficiencies of illuminants. Any useful, exact, quantitative evaluation of radiation as light demands a better considered definition than this. Such a definition is that officially adopted by the Illuminating Engineering Society, namely, that "luminous flux is radiant power evaluated according to its capacity to produce the sensation of light." This definition tells us at once what weight is to be attached not alone to invisible radiations, such as those beyond the violet, but to that inefficient radiation at the ends of the visible spectrum which has furnished so large a share of the "visible" energy in the luminous efficiency determinations to which reference has been made.[1] It presupposes the existence of a definite determinable *evaluating factor,* the stimulus coefficient or luminous efficiency, upon which more will be said in discussing the eye.

Enough has here been said on the nature of light to make clear the backbone of all schemes for physical photometry, namely, the

[1] Ives, H. E., Luminous Efficiency; TRANS. I. E. S., vol. V., p. 113.

measurement of radiation. We shall see, however, that the further refinement of making the proper evaluation as light is not necessary for all the purposes for which the physical photometer has been desired.

THE EYE AS A MEASURING INSTRUMENT.

There are in general two types of measuring instruments, those which indicate by the actual magnitude of their response, and those which indicate the equality or lack of equality of two compared stimuli. The first of these types is well illustrated by the common switchboard ammeters and voltmeters, from which the current or voltage is read off directly by the position of a pointer on a scale. The second type, sometimes called "null" instruments, is illustrated by the potentiometer with its sensitive galvanometer used to detect the condition of no potential. In general the null type of instrument can be made to yield greater sensibility, but this must be paid for by greater complexity of apparatus.

The eye belongs in the class of null instruments. It is common knowledge that one can make only the crudest estimate of candle-power by looking at a light, no matter what one's previous experience. Nor is it possible to estimate with any degree of accuracy how much brighter one light or illuminated surface is than another alongside. What the eye can do, and do very well, is to decide when two adjacent surfaces are equally bright. That is, the eye can take the place of the galvanometer in a potentiometer. Just as the latter tells when there is no difference of potential applied to its two sides, so the eye tells when there is no difference of brightness. Just as in the potentiometer we get at our measure of relative potentials by knowledge of the conditions of resistance and the value of the voltage standard, so in photometry we arrive at our result by knowing the distances between lamps and screens, the value of the standard and the transmissions of various auxiliaries.

When so used the sensibility of the eye to small differences is quite high. Differences of the order of magnitude of ½ per cent. are sufficient to register as inequality. This degree of sensibility is probably quite sufficient for present technical needs.

For scientific purposes, cases might of course arise where greater sensibility would be advantageous.

So far nothing has been said about color, or more properly, color differences. As long as the two lights under comparison are of the same color a condition of equality can be decided upon. But if the lights are different in color the one condition under which the eye has a high degree of precision is lost.

The relative apparent brightness of two adjacent colored surfaces is, with an individual eye, a function of the illumination, of the size of the surface, of the surroundings, of the past history of the observer. It may be determined with more or less precision and with varying results by different photometric methods.

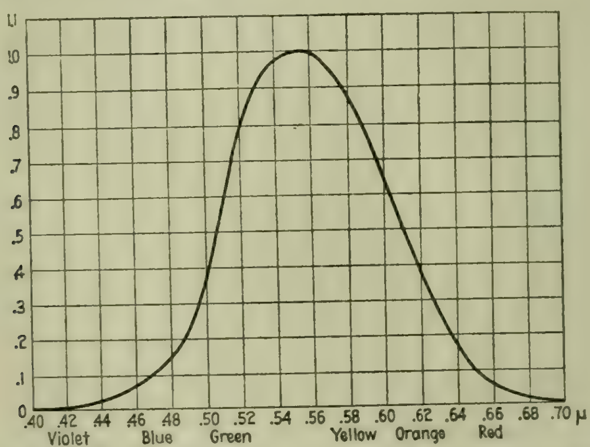

Fig. 1.—Relative luminous efficiencies of the various spectral radiations. (Average normal spectral luminosity curve of eighteen observers for an equal energy spectrum.)

If another eye is used a different result may be obtained. Hence it is that the evaluation of radiant power "according to its capacity to produce the sensation of light" is not a simple matter. It is my belief, however, that as a result of a thorough study of photometric methods in relation to color, evaluation factors can be determined applicable to the great majority of practical cases. Such a set of evaluating factors constitute a spectrum luminosity curve of the average eye. Such a curve is shown in Fig. 1.[2] It will be assumed in what follows, without further discussion, that the question of color in physical photometry is completely cov-

[2] Ives, H. E., The Luminosity Curve of the Average Eye; *Phil. Mag.*, Dec., 1912.

ered by the common adoption of a definite luminosity curve or luminous efficiency curve of the spectrum.

WHAT IS SOUGHT IN AN ARTIFICIAL EYE?

The various goals sought in physical photometry owe their origin to dissatisfaction with one or another of the limitations of the eye just discussed. They should be listed and discussed separately, as will now be done, although various combinations of desirability and feasibility will be found, which will make any classification merely of temporary aid. A helpful preliminary division is into the cases where there is no color difference and vice versa.

A. *Where there is no color difference*—(1) Indication by position rather than by quality. Probably one of the most insistent demands for the physical photometer has its root in the desire to avoid the consideration of quality, substituting for it the estimation of position. Thus while the eye can detect a difference of brightness of ½ per cent. it is probably almost universally true that observers practised and unpractised much prefer to have this difference indicated by the movement of a pointer over a scale. There are several reasons for this. For one thing the great majority of our measuring instruments are of this type. I know of but one instrument where a quantity which could be measured by a moving pointer is indicated by the intensity of illumination, and in this case it is done because the other factor in the comparison cannot readily be shown by positional indications.[3] For another thing most of our measuring instruments have a comparatively enormous store of power to draw upon, so that the problem of getting large deflections is the least to be faced. As we shall see later, the condition is far different with light measurement. Again, the eye is probably working at higher efficiency in estimating the position of a pointer than in estimating equality of brightness, for quality discrimination is at its best with the black pointer and divisions on a light background, and binocular vision and the possibility of movement render our determination of position very exact. At any rate this desire for positional indication rules no matter whether readings are to be made by null method or by proportional indication.

[3] Ives, H. E., A New Form of Watts Per Candle Meter; *Electrical World*, June 8, 1912.

(2) Proportional indication. A very common demand made of a physical photometer is that it shall indicate luminous intensity by the *magnitude* of the deflections of a pointer. In short, that we may by this means be freed from the limitations of the null method, for which the eye is alone capable. A great advantage of this over the null method lies in the consequent simplification of apparatus. It enables us to dispense with the comparison lamp, with the moving carriage and, in fact, with the whole photometer track.

(3) High sensibility. Two kinds of sensibility must be distinguished. First is what may be called total sensibility measured by the amount of light which may be detected. Thus, as we know, the eye can see under illuminations extending all the way from thousands of meter-candles down to thousandths. Our chief interest in sensibility in a physical photometer at present is to obtain even that total sensibility necessary to measure ordinary working illuminations of the order of 10 meter-candles.

The second kind of sensibility is the capacity to detect small differences. It has already been stated that the present attainable differential sensibility with visual photometry is high enough for most practical purposes. This sensibility is, however, the limit we may expect, unless some new principle like the contrast principle of the Lummer-Brodhun should be found. If higher sensibility is ever necessary it must be sought in the physical photometer, to which there is apparently no inherent limitation to sensibility, whatever may be the present practical limitations. Such greater sensibility might, however, be purchased only at the price of simplicity; the null method would probably be necessary, leaving as the only advance over the eye (apart from the greater sensibility) indication by position.

(4) Simple method of response. Where there is no question of the use of color filters to alter the wave-length sensibility of the sensitive surface the advantage of some simple mode of response, such as response directly proportional to stimulus, is exactly on a par with that in any measuring device. Perhaps the most desirable scale would be one giving the same increment of deflection for the same percentage change of stimulus in all the most used parts of the scale (Fechner's law). The most generally useful scale is one giving directly proportional deflections.

(5) Constancy. A physical photometer whose indications were absolutely constant from time to time would be the acme of desirability. Especially is this desirable if its indications are not according to some simple law. In this case the labor of recalibrating after change would be very difficult. If, on the other hand, some simple law is followed, constancy over long periods of time is not absolutely essential. Frequent checking with a standard is too common a procedure in exact measurement to be a serious drawback.

(6) Recording capacity. In line with the modern wide use of recording instruments, we may note that a recording photometer would have much the same reasons for use in technical light measurement as recording pyrometers have in heat or temperature measurements.

(7) Integrating capacity. A photometer which could store up its impressions would have certain uses. For instance it would simplify the measuring of fluctuating light sources such as certain arc lamps. It would as well offer possibilities in measuring the quantity of *light* delivered, in distinction to gas or electrical energy, for which the public service company now has to charge, thereby shouldering all the cost of increased efficiency in lighting means.

(8) Practicability. Various paramount considerations with respect to total sensibility and to convenience may be grouped under "practicability." Thus every desirable feature so far mentioned would be of no immediate practical value if the physical photometer could be operated only in a specially built laboratory and under certain weather conditions. All sensitive apparatus is necessarily delicate, and it therefore becomes necessary to know whether the physical photometer is to be feasible only in the standardizing laboratory, or in the industrial laboratory, or in the field, and what its limitations will be in each case.

B. *Where there is color difference.*—To the desirable qualities which have just been enumerated must be added another which is indispensable if lights of different colors are to be compared. The sensitive medium must be affected by the different wavelength radiations of the spectrum in exactly the same relative amounts as the average eye. The extreme unlikelihood of any

sensitive substance possessing this distribution of sensibility as found lends emphasis to the necessity of a quality already mentioned. The relation between stimulus and response must be of a simple character, preferably it should be rectilinear. Unless this is the case it is not possible to alter the wave-length sensibility curve by the use of absorbing media or equivalent means. This requirement must be met no matter whether the indications are to be by a pointer over a graduated scale or by the null method.

INSTRUMENTS USED TO MEASURE RADIATION.

A detailed description of the instruments available for measuring radiation will not be attempted here, as such descriptions are to be found in the standard physical text books and journals.

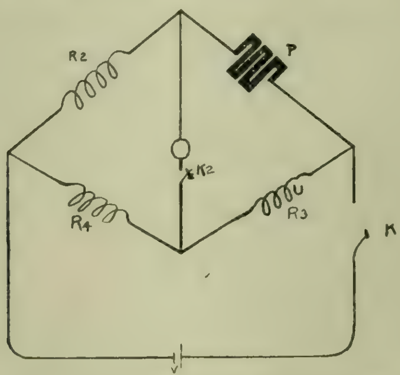

Fig. 2.—Bolometer. The resistance of the thin platinum grid, P, is altered when it receives radiation, thus disturbing the balance of the Wheatstone bridge.

The salient points of each are exhibited in the Figs. 2 to 7 with their attendant legends. Our chief interest here is in classifying and appraising them for photometric needs.

These instruments can be divided on two bases—the basis of sensitiveness, *i. e.*, the quantity of radiation they can measure, and the basis of their behavior to various qualities of radiation, or selectivity, as it is called. For instance, a black bulb thermometer is equally sensitive to all kinds of radiation, visible or invisible, but it takes a very large amount of radiation to produce respectable indications. On the other hand the photographic plate is chiefly sensitive to blue, violet and ultra-violet light, but it is so sensitive that instantaneous photography is a common-

place. It may be noted in passing that there appears to be no exception to the general rule, of which these cases are examples, that great total sensitiveness is obtainable only at the cost of limited spectrum range of sensibility. The eye, with its range of only a single octave of the lengthy scale from X-rays to wireless, is another notable example of this fact.

The chief non-selective radiometers are the bolometer, the thermopile, the radiometer and the radiomicrometer. The first of these, made famous by the researches of Langley, consists essentially of a fine strip of blackened platinum whose electrical resistance is altered with any change in its temperature. Radiation falling on the strip heats it and causes a change of resistance,

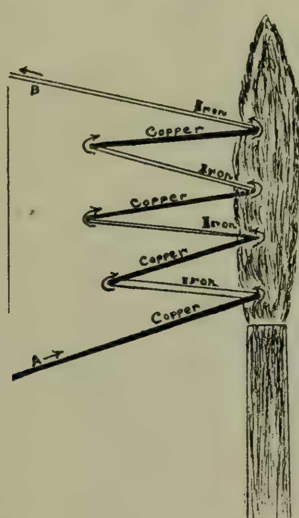

Fig. 3.—Simple thermopile. The unequal heating of the hot and cold junctions causes an electric current to flow.

which is indicated by a sufficiently sensitive galvanometer connected to the Wheatstone bridge system, of which the platinum strip is one element.

The thermopile consists of one or more junctions of dissimilar metals or alloys selected as having a large thermo-electric power. When the junctions are heated by radiation the electromotive force produced is sufficient to drive a small current through a galvanometer connected in series with them. Both of these instruments, it will be noted, necessitate a galvanometer as auxiliary.

8

Their sensibility and practicability are to a large degree conditioned by this limitation. The two remaining instruments of this group are simpler in this respect, being complete in themselves.

The radiometer, developed by E. F. Nichols from the toy devised by Crooks, consists of a light double vane suspended in a partial vacuum. One side of each vane is blackened and when radiation falls on one of these blackened faces the vane is rotated, its motion being shown by the reflection of a spot of light by a small mirror carried on the suspending fiber.

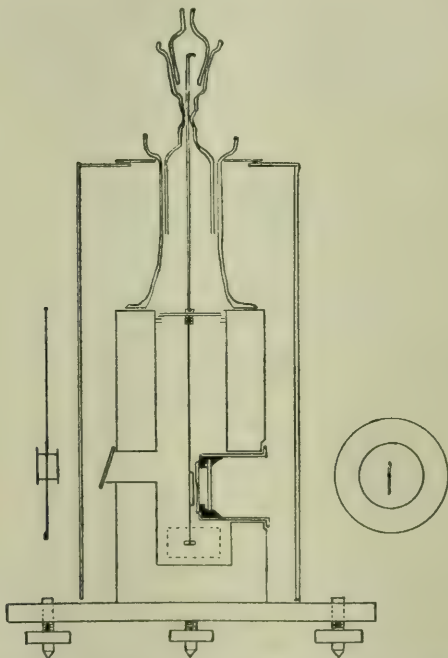

Fig. 4.—Radiometer. The radiation falls on a light vane, blackened on one side, in an evacuated enclosure which is rotated on its support.

The Boys radiomicrometer is practically a thermo-junction between the poles of a magnet. When a current flows through the thermo-junction circuit, due to its heating, the coil of wire to which the junction is attached turns in the magnetic field, its motion being indicated by a beam of light from an attached mirror.

Coming now to selective radiometers, the chief of these are the selenium cell, the photo-electric cell and the photographic plate.

Of these, selenium has perhaps secured the greatest notoriety. The applicability of this remarkable element is due to its property of changing its electrical resistance under the action of light. Consequently when connected in series with a source of electromotive force and a sensitive galvanometer, the illumination or obscurement of the sensitive surface is detectable.

The photo-electric cell, in particular when constructed from one

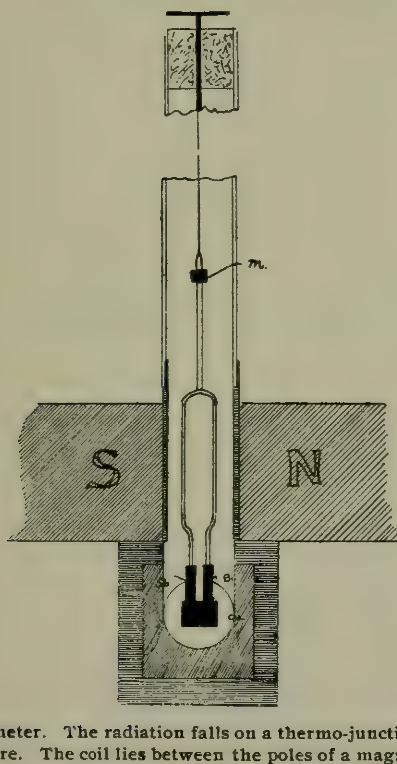

Fig. 5.—Radiomicrometer. The radiation falls on a thermo-junction which is carried on a small coil of wire. The coil lies between the poles of a magnet, and when radiation on the thermopile causes a current to flow, the coil rotates.

of the alkali metals, is one of the most interesting and lately most studied possibilities in this line. In brief, an alkali metal surface, preferably in a vacuum or partial vacuum, when illuminated gives off negative electricity. When connected with an electrometer or a sensitive galvanometer (there are several different methods of arranging the apparatus) a current flows upon the illumination of the surface. The last of these selective physical photometers

to be mentioned here is the photographic plate, which is the best known example of chemical change produced by light. From our standpoint the photographic plate is a means of recording the amount of incident light by the amount of deposited silver. It is quite distinct from all the preceding means considered in that it requires nothing in the way of an auxiliary galvanometer or conditions of extreme freedom from vibration.

These three instruments just considered have been grouped

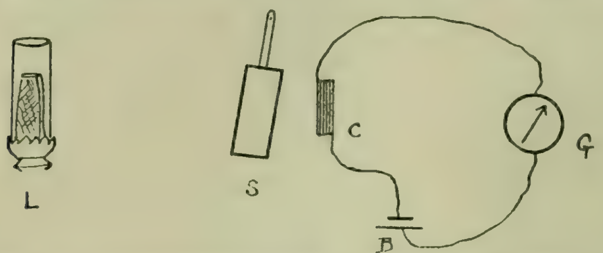

Fig. 6.—Selenium cell and connections. L, light source; S, shutter; C, selenium; D, battery; G, galvanometer.

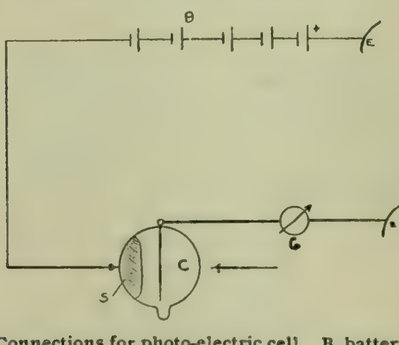

Fig. 7.—Connections for photo-electric cell. B, battery; C, cell; G, galvanometer; E, earth.

together for the reason that they are not, in their natural condition, equally sensitive to all qualities of radiation. Thus the selenium cell, speaking roughly, is sensitive chiefly to radiations near the visible. The photo-electric cell, of sodium, potassium, rubidium or caesium, is chiefly sensitive in the ultra-violet, but increasing toward the visible region in the order given. The photographic plate is normally most sensitive to the blue, violet and ultra-violet. By means of sensitizers however it may be made sensitive as far as the deep red.

DISCUSSION OF THESE INSTRUMENTS AS PHYSICAL PHOTOMETERS.

It will now be our task to discuss each of these instruments with reference to the desirable qualities previously outlined. From this discussion one may hope to determine in what lines of work physical photometry is apt to be of practical value now or in the near future.

At this point it becomes necessary to study the *quantity* of radiation involved in what we have decided to call light, in particular reference to the sensibility of the instruments we have been considering. For some reasons it would be preferable to reduce all the quantities involved to absolute units, but we may for our present purpose save much time by utilizing the fortunate fact that the sensibility of radiometric instruments is usually expressed in terms of the effect produced by a candle at a meter's distance—our own familiar meter-candle. Thus it is found that, using the most sensitive instrument yet constructed of the class of the bolometer, radiometer and thermopile, a deflection of 50 centimeters per square millimeter of sensitive area is of the order of magnitude obtainable.

Now the most recent determination of the luminous efficiency of the 4-watt electric lamp is 0.45 per cent. Consequently a 16 candlepower lamp at a meter distance, which gives no inconsiderable illumination, would, if measured through a proper light-evaluating screen, give only 4 millimeters deflection. And this is under the most refined laboratory conditions, with the most perfect freedom from mechanical disturbance, and from changes in the temperature of the surroundings. Reference to Fig. 8, where the total radiated energy, and the energy evaluated as light are shown, tells the same story. These illustrations bring us at once to the most serious problem in physical photometry. The amount of energy available as light is of *excessive* smallness. This difficulty can be met and is being met in various ways. In some of the instruments the exposed area may be made greater than one square millimeter; means are being studied to increase the intrinsic sensitiveness, such as evacuating the surrounding space; greater freedom from the effects of changes in the local temperature is obtained by instruments of the compensated type;

and every year brings improvements in the sensibility and ruggedness of sensitive galvanometers and other auxiliaries. How far we have progressed in this direction is shown below, where actual practical examples are given wherever practicable.

A. *The Non-Selective Instruments.*—The bolometer, radiometer, radiomicrometer and thermopile may be treated in practically the same description. First, the case where there is no question of color difference; for instance the measurement of two electric incandescent lamps of identical color. These instru-

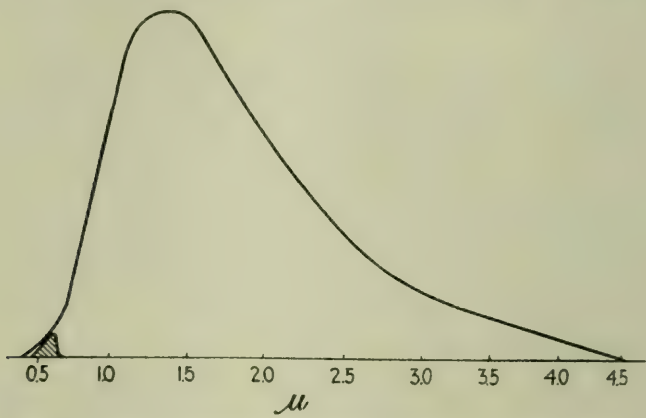

Fig. 8.—Ratio of luminous flux to radiant power in the carbon lamp. Small area, luminous flux.

ments possess the simplest mode of response, that is, their indication is directly proportional to the intensity of the incident radiation. They therefore lend themselves to the problem of reducing our measurements to a positional basis and in that way to simplification of apparatus. Their practicability depends chiefly on the amount of radiant energy available. Since there is no question of color difference, we frequently meet with the possibility of utilizing a large amount of invisible energy to help out. Thus with the two incandescent lamps we are considering if we measure the total energy instead of simply the visible we have at least 100 times as much at our command, and this means the difference between delicate laboratory conditions and the ordinary photometer room. Whether this opens up a really valuable possibility or not depends on whether the light and the total energy are always proportional in the two supposedly similar

light sources. In many cases this is true. A practical example of a promising field for the utilization of total energy measurements to secure positional indications is the reading of gas flame candle-powers. So much energy is here available that with a string galvanometer and a large area surface thermopile it should be possible not only to read but automatically to register candle-powers by the photographic registration of a moving spot of light or similar sensitive method.

A considerable degree of constancy is to be expected in the readings of these instruments, sufficient at least so that checking with a standard at occasional intervals during a series of measurements would be sufficient. The possibility of securing greater differential sensibility than with visual photometry is not to be anticipated, particularly where one is compelled to use the invisible energy to obtain workable deflections.

But so few and of so little importance are the cases where we work with lights of exactly the same quality that the slender possibility we have just considered is of little more than academic interest. This is shown by the fact that practically all the recorded attempts to use these radiometers in photometry have involved some scheme for approximating the luminosity curve of the eye.

Turning, then, to the case of photometry with a color difference, we find that the first difficulty with the non-selective radiometers is that they are not sensitive to radiation as is the eye, but to the whole scale. This has two consequences, first, that some means must be adopted to alter the wave-length sensibility and, second, as already pointed out, that when this alteration is made, the remaining sensibility is extremely small.

However, since these instruments possess the simplest mode of response, it is feasible to alter their distribution of sensibility, and the fact is that at the present time the only truly satisfactory physical photometer is of this type. Before describing this instrument, recently developed in the United Gas Improvement Company's physical laboratory, historical mention should be made of earlier instruments of the same type.

Fery,[4] in 1908, constructed and used a radiomicrometer over

[4] Bull. Soc. Franc de Physique, 1908, p. 148.

which was placed an absorbing solution of copper acetate to obstruct the infra-red radiation and to cut down the "visible" roughly in proportion to its luminous efficiency. This instrument though crude was on the right principle and proved the feasibility of the scheme. It was used quite extensively by Fery in his studies of the power relations in the incandescent lamp. In 1911 Houston,[5] in connection with his proposal for a primary standard of light, described a combination of two solutions—copper sulphate and potassium dichromate—which give a close approximation to the best determination at that time of the luminosity curve of the spectrum. These solutions used with a radiometer constitute a physical photometer calculated for lights of any color. Recently Dr. Karrer, at my suggestion, worked out

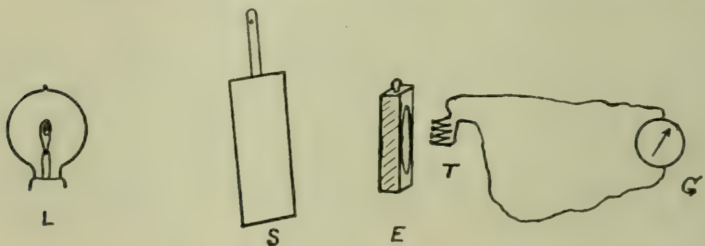

Fig. 9.—Thermopile artificial eye. L, light source ; S, shutter ; E, luminosity curve solution ; T, thermopile ; G, galvanometer.

a combination of three solutions in separate tanks, whose total transmission is very closely the luminosity curve of the spectrum according to the latest determinations. This solution has been used to make determinations of true luminous efficiencies, but is immediately applicable to photometry.

Benefitting by this previous work I have recently been able to develop a visual luminosity medium, complete in one solution, approximating practically perfectly to the luminosity curve as previously determined by him. This has been set up in front of a sensitive surface thermopile, thereby making an artificial eye exactly corresponding to the real normal eye under the adopted standard photometric conditions (Fig. 9) and indicating positionally by the relative deflections of a pointer.

Now, all attempts hitherto made in this direction have labored

[5] Proc. Royal Society A, 1911, p. 275.

under the great disadvantage that there has been no means of determining whether the instrument's readings were right. The convenience and precision of the former devices was generally recognized, but whether their readings actually corresponded to the true ones could not be established, because no standard method of colored light photometry had been developed; nor were there any standard reproducible colors that had been measured by any photometric method. Recently in a paper[6] before this society a colored absorbing solution of very useful qualities was described, together with complete measurements by the method of colored light photometry developed by the writer. With these various means at hand it has been possible to bring this problem to a definite and successful conclusion. We have carried through with our physical photometer the same measurements made visually with the result shown in Fig. 10. The agreement is so perfect that we are now using the physical photometer directly in those cases where the solutions had already made possible enormous simplification of work. We now use this device to calibrate incandescent lamps of any color and for the standardizing of colored glasses for use in visual photometery to eliminate color differences in practical work. We are by this means enabled to secure accurate and satisfactory results in a few minutes which previously required the cooperation of a large number of observers and several days work.

The limitations of this device are those already enlarged upon, namely, it is strictly a laboratory instrument. It is operated in a basement as free as possible from vibration and large temperature changes. It must be used with rather high candlepower sources as close as possible to the receiving surface. But these are not serious limitations at all from the standpoint of those standardizing laboratories in whose hands will rest the calibration of color difference eliminating media. It is to the solution of this important problem that we offer this completely developed physical photometer.

B. *The selective instruments.* Of the selective instruments the first to claim attention is the selenium cell. This has attracted a great deal of attention and justly so, for it actually rivals the

[6] Ives, H. E., and E. F., Kingsbury, Experiments with Colored Absorbing Solutions for Use in Heterochromatic Photometry; TRANS. I. E. S., vol. IX, No. 8.

eye in sensitiveness. That is, it makes possible the translation of illuminations within the range to which the eye is accustomed, into movements of a pointer of a magnitude easily appreciated. By so doing, as already pointed out, not only is photometric reading made easier but half of the photometer bar or its equivalent may be dispensed with.

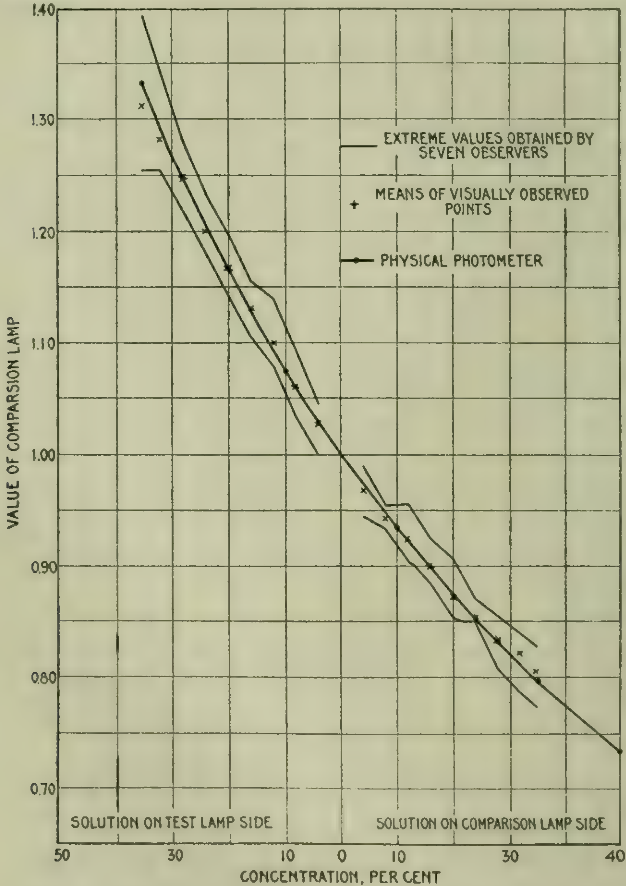

Fig. 10.—Comparative results, visual and physical photometers.

The error of many who have tried to use the selenium cell is in their assumption that this is all that is needed to fit a physical photometer for the attack of any problem. We may quickly differentiate between the use and abuse of the selenium cell by reference to the various qualifications previously enumerated.

On the standpoint of sensibility and practicability it ranks high. Thus it is possible with a cell of large area, using dry cells as source of e. m. f., to obtain satisfactory readings, on a portable millivoltmeter, of ordinary artificial illuminations. These are defects in the way of inertia, changing sensibility and the like, which, however, can be largely met by a fixed procedure in exposing and by mounting the selenium in an evacuated space.

Going at once to the question of behavior toward light of different colors, a very peculiar and interesting state of affairs is found. The wave-length sensibility curve of selenium is not the

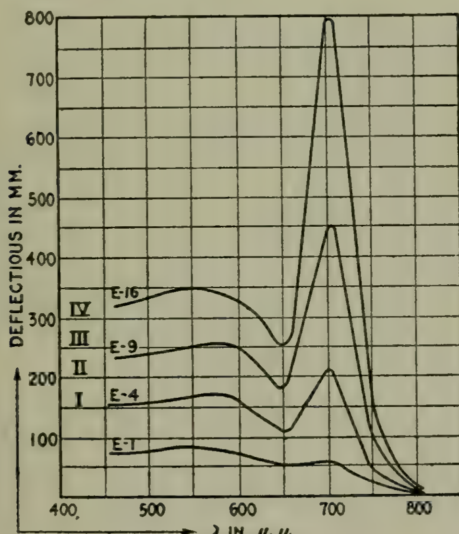

Fig. 11.—Wave length sensibility curves of selenium for various intensities of light.

same as that of the eye. This alone is not fatal, provided the substance is sensitive to all visible radiations, as selenium is, for a sensibility curve may be altered as was shown in the case of the radiometers. It is questionable whether any two selenium surfaces will be apt to have exactly the same distribution of sensibility through the spectrum, which is a serious drawback, as it would make each cell an individual problem to manufacture properly screened. But more serious than this is the fact that the method of response is different for different colors. For

most of the visible and ultra-violet spectrum the response is as the square root of the stimulus, while for the deep red it is directly as the stimulus.[7] As a consequence any absorbing medium or equivalent means for producing a desired distribution of sensibility through the spectrum is rendered worthless. This is clearly shown by the wave-length sensibility curves for different intensities of illumination exhibited in Fig. 11. While an absorbing medium could be provided to take care of either of these methods of response, nothing will take care of both.

What then is the field for selenium in photometry? This: the measurement of radiation of definite fixed quality upon which the apparatus has previously been calibrated. As long as the apparatus is used throughout on this same radiation all is well, but immediately lights of different quality are to be measured and selenium is of no value to us, no matter how great its sensibility or convenience. Selenium is now being used successfully in scientific investigations where monochromatic light must be evaluated under conditions where the much less sensitive radiometers would be out of the question. It could be used to measure artificial illuminations with great advantage over visual photometers. But if so used it would, after being calibrated on a carbon lamp, measure only carbon lamps correctly.

Our discussion of the next selective instrument—the photo-electric cell—may be considerably shortened by reason of the fullness with which the previous instruments have been treated. The photo-electric cell containing one of the alkali metals lies between the non-selective radiometers and selenium in its total sensibility. Connected with the proper sensitive auxiliaries, it has been found sensitive enough to detect the illumination from a single match yards away. A cell of large area of the most sensitive type will record daylight illuminations on a portable galvanometer, and with a voltage supply of 50 to 100, which can be made portable, artificial illuminants can be at least detected. The photo-electric cell has attracted much attention of late because it has been thought that its indications are directly as the intensity of the incident illumination. It has been thought, too, that since its color sensibility extends into the visible spectrum, it

[7] Pfund, A. H., The Use and Abuse of the Selenium Cell in Photometry; *Lighting Journal*, 1913.

should be possible to apply absorbing media, as in the case of the thermopile artificial eye but with greatly increased sensibility. In fact Dr. Voege has recently described experiments with such an apparatus. All these hopes were fated to be blasted, for the present at least, by recent work which has shown that the response to light is not directly as the intensity, but is a complicated function of several factors, and is as yet quite uncontrollable.[8] The illumination-current relationship for a number of cells is shown in Fig. 12.

A still further objection to the photo-electric cell is that the

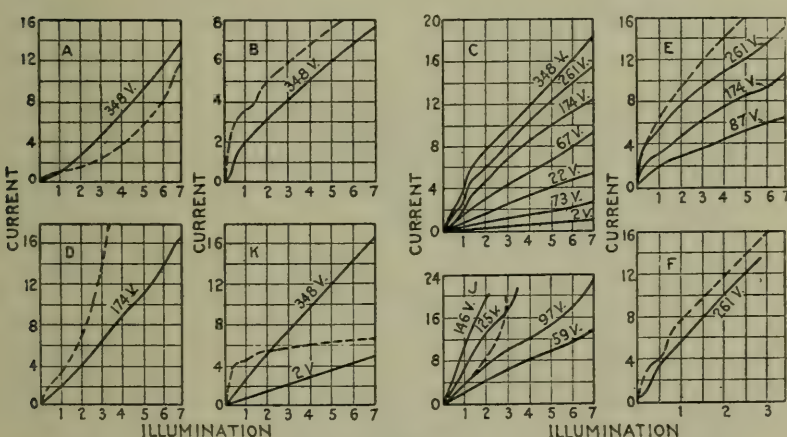

Fig. 12.—Illumination-current relationship in various photo-electric cells.

wave-length sensibility does not appear to be the same from one cell to another,[9] a point exhibited in Fig. 13. Another point exhibited by the latter figure is that the maximum sensibility of these cells lies far out in the violet of the spectrum. Consequently the amount of available energy after an appropriate absorbing medium has been introduced to make them read "light" is quite small. The presence of these two defects in the photo-electric cell must defer its consideration in this connection until its properties have been much more thoroughly studied.

[8] Ives, H. E., The Illumination-current Relationship in Potassium Photo-electric Cells; *Astrophysical Journal*, June, 1914.

[9] Ives, H. E., Wave-length Sensibility Curves of Potassium Photo-electric Cells; *Astrophysical Journal*, Sept., 1914.

The fact that neither the selenium cell nor the photo-electric cell lend themselves to any method of copying the wave-length sensibility curve of the eye makes it possible to subject them both to the sweeping criticism that they do not measure *light,* as we have defined it, at all. Under certain restricted conditions they measure radiations which under those conditions are proportional to light.

We now come to the last of the means for physical photometry

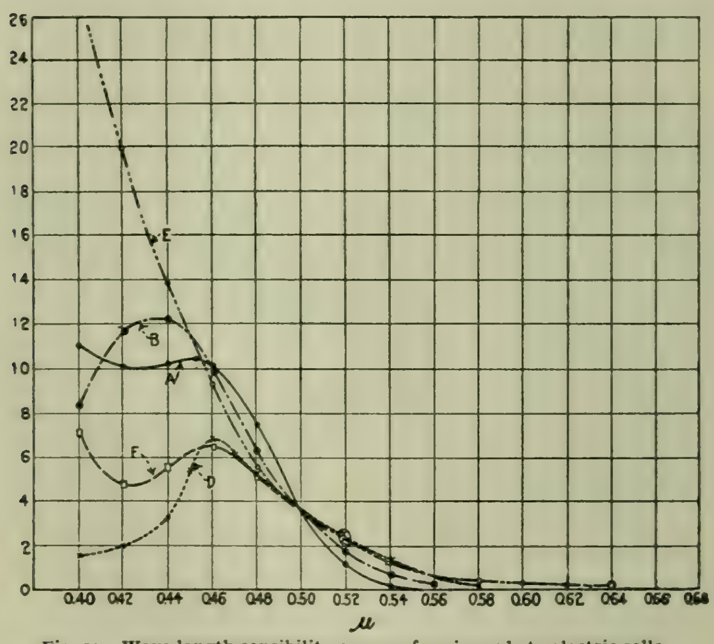

Fig. 13.—Wave-length sensibility curves of various photo-electric cells, reduced to equal energy spectrum.

that we shall consider, namely, the photographic plate. Perhaps the most striking difference between it and the instruments we have been considering is that in its use we definitely abandon any attempt to secure direct positional indication. The photographic record when obtained must itself be measured, and in this measurement either the ordinary photometric methods or some radiometric scheme must be employed. It goes therefore almost without saying that the photographic plate is not resorted to for convenience. In ordinary photometry it would only introduce extra

work without any gain, unless the plate could be measured with greater precision than could the original illumination, which is hardly likely. Resort to photography is then only to be expected if there are some things the plate can do well enough to offset this disadvantage.

The photographic plate has extreme sensibility, as already pointed out. It can be made sensitive to the visible spectrum as shown in Fig. 14. Its response is, over a considerable range of intensities, proportional to the stimulus.[10] It presents thus far no great advantage over the eye. Its most striking peculiarity is that it can integrate, not only the effects of very faint stimuli but, with some limitations, fluctuating or changing stimuli. This

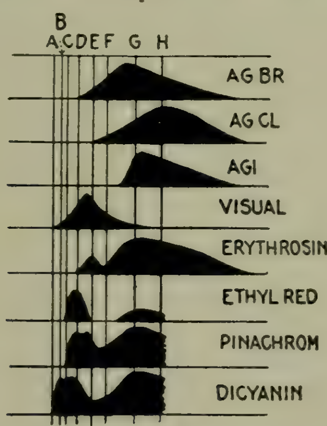

Fig. 14.—Sensibility of photographic plates sensitized and unsensitized, to different regions of the spectrum.

property is chiefly taken advantage of in the measurement of faint spectra, such as that of the fire-fly and in other cases where, as above pointed out, the measurement is not really that of light but radiation. Some use has however been made of photography to measure as light the irregular distribution curves of arc lamps, which because of the unsteady character of their light are difficult for ordinary photometry.

The photographic process is very sensitive to many disturbing influences. To avoid the errors these influences may cause, it is necessary to use careful substitution methods, and to adhere to

[10] Ives, H. E., The Application of Photography to Photometry; TRANS. I. E. S., vol VII, p. 90.

very carefully worked out procedures in exposure and development, all of which conspire to deprive the photographic methods of photometry of precision, leaving their field restricted to cases where photography will do something nothing else will.

SUMMARY.

In this paper an attempt has been made to clarify the question of physical photometry, first by determining what it is we want to measure; second, by tabulating the qualities which would be desirable in instruments to take the place of the eye. It has been found that the various desirable qualities are found scattered among a number of instruments, none of which possesses enough to give it a claim to be a universal "light" measuring device. At the present time only one instrument, the non-selective radiometer with a proper evaluating absorptive medium, does actually perform as an artificial eye. Its limitation is its comparative insensitiveness, which restricts its use to the laboratory, where however it has a field of great usefulness. For the much greater sensitiveness of some of the devices to become available we must look to future developments.

WHAT WE MAY EXPECT IN THE FUTURE.

The history of the measurement of radiant energy is a record of continually increasing sensibility of instrumental means, followed by the transfer of these more sensitive means from the laboratory to the technical stage. Thus within a few years the thermopile has been made much more sensitive by the use of new substances for the thermo-electric junctions, by study of the best dimensions, by new processes of evacuation. More and more sensitive galvanometers have been built, and, what is more to the point for the present purpose, increasing ruggedness and practicability have been attained, especially in the string types of galvanometer. In view of these facts it is not unreasonable to hope that before very long the successful type of physical photometer which has been described here may be available for many other than standardizing purposes.

On the side of the selective means a truly enormous amount of work is being done. The photo-electric cell in particular, be-

cause of its bearing on many important points in physical theory, is the object of wide study. The relation between illumination and current, and the differences in wave-length sensibility in various cells of the same composition, are subjects under study, and with increased knowledge it is to be expected that we shall acquire control of the disturbing factors. That accomplished, we shall hope to utilize the enormous sensitiveness of this class of instrument and at the same time make them measure light.

AN APPROXIMATE UNIFORM PHOTOMETRIC POINT-SOURCE.*

BY A. E. KENNELLY, R. W. CHADBOURN AND G. D. EDWARDS.

Synopsis: Experiments are described on a modified form of frosted tungsten 100-watt spherical stereopticon lamp with a view to producing a uniform virtual point-source. The measurements show that exempting an axial cone, at each pole, of 45 deg. semi-angle, or 29.3 per cent. of the total spherical area, the maximum deviation ratio of the lamp (the ratio of the maximum deviation of the intensity to the mean spherical intensity over the retained area) was 4.65 per cent.

A luminous point-source may be defined as a source of light condensed in so small a volume as virtually to constitute a mere point in space for the purposes under consideration. Such a point-source would be specially serviceable for placing at the focus of a parabolic reflector in the production of a parallel beam of light. A point-source to serve for a projector does not need to distribute light uniformly in all directions. It only needs to radiate light from a central point.

In the theory of photometry, however, it is customary to start with the simple concept of a *uniform* luminous "point-source," or an ideal lamp which distributes light uniformly in all directions, as though the source were concentrated at a single point. No lamp can be produced to comply with such a concept. There must always be an appreciable surface-area in the luminous source, and this surface is seldom even approximately spherical. It is supported by a more or less opaque structure, in a chamber whose walls are not uniformly transparent; so that the distribution of luminous flux is frequently very far from being uniform in different directions, even at long radial distances from the lamp. At short radial distances from the lamp, the distribution of light is apt to depart still further from uniformity. In actual service, this departure from the condition of a simple uniform luminous point-source is not of great consequence, except that

* A paper presented at a meeting of the New England Section of the Illuminating Engineering Society, November 10, 1914.

whereas from a photometric standpoint, a single measurement of candlepower taken in any direction would completely specify a uniform point-source, the ordinary non-uniform radiator requires to have its candlepower measured in many directions, in order adequately to specify its photometric properties. We also know that for particular purposes in illumination, a marked departure from uniform distribution may be desirable; as, for instance, when a lamp is needed to emit a strong beam of light in a selected direction.

Nevertheless, there would be a certain convenience in the photometer room, if a virtual uniform point-source were available; *i. e.*, a source which, although of appreciable dimensions, would emit light uniformly in different directions and, under its conditions of use, would act substantially as though this light emerged from a point. Standard incandescent lamps are ordinarily calibrated for mean horizontal intensity when rotating, or for a constant intensity in one geometrically defined direction, when fixed with this direction along the axis of the photometer bar. A virtual uniform point-source would make rotation unnecessary in the first case, and the marking of the fiducial direction unnecessary in the second case. Such a lamp would be easy to set up, and to calibrate in a photometer. It could only be expected to serve as a *virtual* point-source at a suitable photometric distance; because no light source can be produced at a mere point, and, at very short ranges, actual luminous surfaces must be expected to depart widely from point-source conditions.

A virtual point-source photometric standard would also have the advantage that its mean spherical reduction-factor would be unity, and its total flux of emitted light would be just 4π times its intensity as measured in any direction. A rough criterion of the degree of approximation offered by any lamp to a point-source, is its spherical reduction factor with respect to 1.0. A lamp with a spherical reduction factor differing materially from 1.0 must differ materially from a point-source at the photometric distance considered. On the other hand, a lamp might have a spherical reduction factor of 1.0, and yet might differ greatly from a point-source. For example, it might happen to have a mean horizontal candlepower just equal to its mean spherical

candlepower, and yet display considerable irregularity in candlepower in different zones. A strict definition of deviation from the point-source condition at a given radius of measurement might be stated as the greatest difference between actual candlepower in any direction and the mean spherical, divided by the mean spherical candlepower. This might be called the point-source deviation ratio of the lamp, for the radius of photometric observation considered. If applied over the entire sphere, however, perhaps no existing lamp could possibly escape a large deviation ratio; because in the case, say of an incandescent lamp, where the conducting wires entered the lamp, a shadow would have to be cast, and the deviation from mean spherical candlepower would have to be considerable along the direction of this shadow. Nevertheless, the practical utility of the definition might be fairly well maintained by expressing some reservation for the shadow cone. Thus, if an incandescent lamp had a shadow near its base comprised within a right cone of, say, 45 deg. semi-angle, within the apex formed at the optical center of the lamp, as indicated in Fig. 3, the mean spherical candlepower might be reckoned to the exclusion of this basal shadow zone. Over the rest of the sphere, the deviation from the mean spherical candlepower thus delimited might conceivably be reduced to insignificance at distances beyond one meter. Such a lamp would be a virtual uniform point-source at and beyond meter-distance, except within the 45 deg. conical zone comprising the lamp-base. In general, the ratio of point-source deviation for such lamps could be reduced by increasing the size of the exempted zone; until, however, the exemption became so large that the utility of the lamp as a virtual point-source became seriously restricted. With an axial cone of semi-angle 45 deg. as in Fig. 3, the exempted area would be vers 45 deg. $= 0.293$ of the hemisphere surrounding the cone, and with 45 deg. axial cone at each pole the exemption would be 0.293 of the whole sphere. That is, the retained area would be 0.707 of the whole sphere. Expressed in solid-angle measure, the retained angle would be $0.707 \times 4\pi$ steradians and the exempted angle $0.293 \times 4\pi$ steradians. In general, with an axial cone of semi-angle θ exempted at each pole, the retained area would be $\cos\theta$, and the exempted area $\operatorname{vers}\theta = 1 - \cos\theta$, taking the whole area of the sphere as unity.

Several unsuccessful attempts were made by the writers to find an existing type of lamp which might approximate a uniform virtual point-source. The lamp department of the General Electric Company assisted us, however, by preparing a modification of one of their tungsten 100-watt stereopticon lamps of the spherical frosted type with a concentrated spiral tungsten filament. This type of lamp is illustrated in Fig. 1. Its external diameter

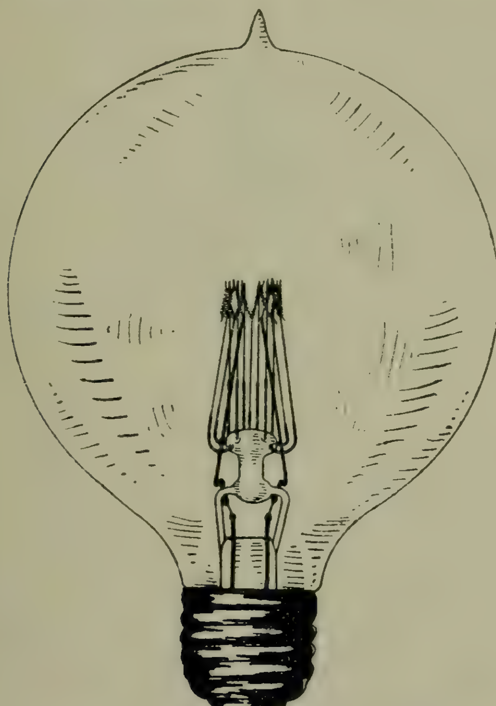

Fig. 1.—Diagram of a 100-watt concentrated, tungsten-filament stereopticon lamp 3¾ in. in diameter.

is 3.75 in. (9.53 cm.). The tungsten wire filament is first wound in a spiral approximately 1 mm. in diameter. This spiral is then looped up and down in a crown of 10 hook-supports indicated in plan by Fig. 2. Two lamps of this type were tested, one with a clear globe, and the other with a frosted globe. As might have been expected, the clear-globe lamp was decidedly inferior to the frosted-globe lamp as a uniform point-source; so that we need only consider, in what follows, the results obtained with the

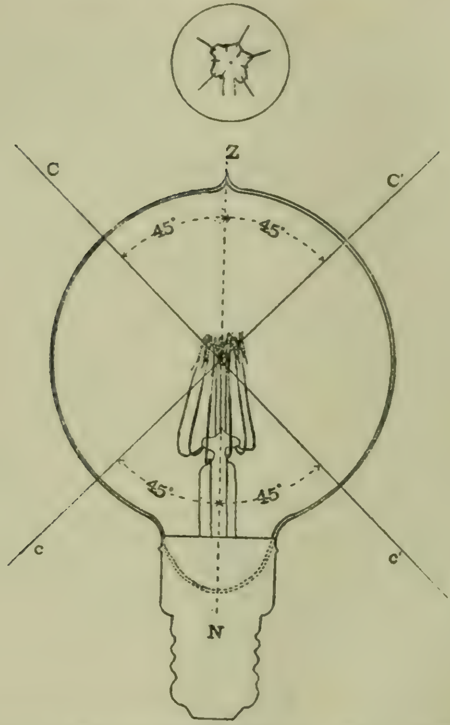

Fig. 2.—(Upper diagram) Plan of supported filament. Fig. 3.—(lower diagram) Axial section of a tungsten-filament stereopticon lamp, indicating an exempted cone at each pole of semi-angle 45°.

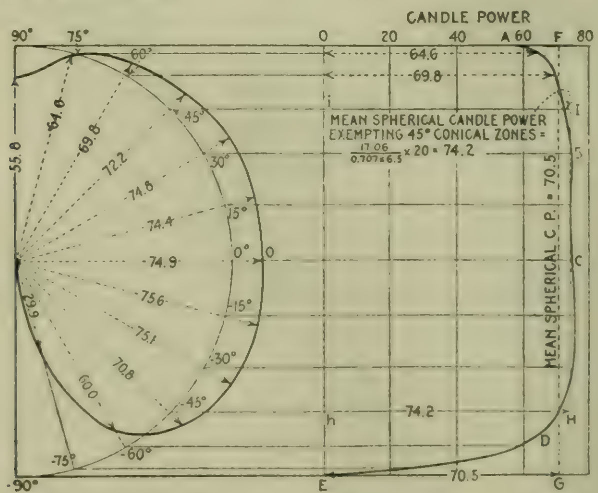

Fig. 4.—Rousseau diagram.

frosted lamp, the globe of which was uniformly and completely frosted.

The lamp was set up in the photometer rotating about its axis about 100 revolutions per minute. There was actually but little candlepower difference in azimuth; so that the test might have been made without rotating the lamp, if the mean of several readings in fixed azimuths at each zone had been taken.

The zonal distribution curve and the corresponding Rousseau diagram are given in Fig. 4. It will be seen that the luminous intensity remains fairly close to 75 candles over a considerable solid angular range. Above an elevation of 60 deg., the intensity falls off to 55.8 at the tip, apparently owing to reduced reflecting power from the walls within the socket. Below a depression of 45 deg., the intensity falls off rapidly, apparently owing to absorption of light by the hooks, and socket. Nevertheless, the mean spherical candlepower comes out 70.5 with a mean horizontal candlepower of 74.9, making a spherical reduction factor of 0.941. It is evident that the curved line A B C D E on the Rousseau diagram of a true virtual point-source would be straight and parallel to the base O E.

The corresponding involute diagram is shown in Fig. 5.[1] Here the successive arcs are drawn in zones of 15 deg. The polar diagram is indicated by the broken line 90 deg., 75 deg., 60 deg., 45 deg., 30 deg., 15 deg., 0 deg., —15 deg., —30 deg., —45 deg., —60 deg., —75 deg. The corresponding involute is A B C D E F G H I J K L M. Half the total projected vertical distance between A and M measures 70.4 candlepower to scale and represents the mean spherical candlepower of the lamp, with a spherical reduction-factor of $\frac{70.4}{74.9} = 0.940$. It is evident that for a virtual point-source, the involute M L K—C D E F would become a true semi-circle, and the evolute, or line of centers P Q R S T U V W X would shrink to a single central point at T.

If we consider the point-source deviation ratio of this lamp after exempting a conical region of 45 deg. semi-angle with re-

[1] Kennelly, A. E., A Rectilinear Graphical Construction of the Spherical Reduction Factor of a Lamp; TRANS. I. E. S., February, 1908. A New Graphic Method for Determining the Mean Spherical Intensity of a Lamp by the Length of a Straight Line when the Curve of Meridianal Intensity is Given, *Electrical World*, March 28, 1908.

spect to the axis; *i. e.*, retaining only the region from —45 deg. to +45 deg. of elevational angle, we find on the Rousseau diagram that the mean spherical cp. is represented by the distance *h* H or *i* I since the area *i* I H *h* is found to be equal to the planimetered area of the curve over the base *i h*. The mean spherical cp. over this exempted area is 74.2. The greatest deviation from

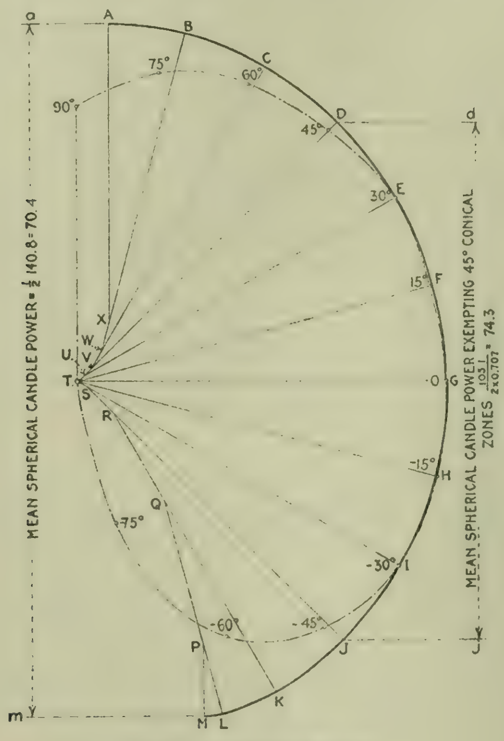

Fig. 5.—Kennelly diagram.

this value over the retained area is at *e* D = 70.8 or 3.4 cp. The maximum deviation ratio is thus $\frac{3.4}{74.2}$ = 0.0458 or 4.58 per cent. As already pointed out, the area retained is 70.7 per cent. of the whole area of the sphere; or the exempted region is 29.3 per cent. Over the entire retained area, the maximum deviation from the mean retained spherical cp. is thus only about 4.5 per cent.

Similarly, in the involute diagram of Fig. 5, retaining only the involute curve D E F G H I J, the mean retained spherical candle-power is half of the vertical distance D J or $\frac{dj}{2}$ divided by 0.707, or 74.3. The maximum deviation over this retained area is $74.3 - 70.8 = 3.5$ cp. and the maximum deviation ratio $\frac{3.5}{74.3} = 0.0471$ or 4.71 per cent. If both the Rosseau and involute diagrams could be drawn without any inaccuracies, their results would, of course, be in agreement. In this case, the maximum deviation ratio may be taken at the average value of 4.65 per cent. over the retained area between +45 deg. and —45 deg. It is evident from either of the diagrams (Figs. 4 and 5) that between +30 deg. and —30 deg. the deviation ratio would be much less, but this would exempt half the area of the sphere.

If the frosted tungsten stereopticon lamp here considered were further modified in structure, the approximation to a uniform virtual point-source could evidently be increased. Thus, the base of the lamp might be removed and replaced by a thin glass tube, or pair of tubes, carrying out the leading wires. Again, the globe might be enlarged, the spherical form continued over the area covered by the present base, and the filament supporting wires arranged for minimum shadow. With all of these amendments, the exempted area might probably be considerably reduced, and the maximum deviation ratio also. Perhaps the maximum deviation ratio might be reduced to 2 per cent. It is hoped that, as a matter of interest, it may be possible to carry on further experiments in this direction.

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SOME USES OF LIGHT IN THE TREATMENT OF DISEASE.*

BY E. C. TITUS, M. D.

Synopsis: The value of light as an efficient remedy when properly employed in the treatment of many painful and diseased conditions is discussed in the following paper. A brief review of the art of applying the therapeutic effect of light is also included.

To many the subject of phototherapy is invested with so much mystery, and its fundamental principles are so frequently imperfectly understood, that it is not surprising that progress in this field has been so slow. Even now comparatively few are making systematic use of this important therapeutic agent. It would consume much more time than is at my disposal to present more than an outline of this subject, and I will therefore confine myself chiefly to its practical therapeutic aspect, as based largely upon my own observations.

From time immemorial the beneficial influence of sunlight upon animal and vegetable life has been recognized, but it is only at the present time that we are appreciating its full value in the treatment of disease.

The excellent and even wonderful results of heliotherapy in the treatment of bone tuberculosis, to which attention has been called within a recent period, will serve as an illustration.

For obvious reasons, however, sunlight is not always available, and it has therefore been found advantageous to resort to other sources of light. Thanks to the progress made in electricity, we now have at our disposal various means of obtaining light closely approaching that of the sun in its remedial action, and to these means, chiefly, my paper will be devoted.

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

Phototherapy may be considered under two heads, its thermic and actinic effects, although both of these are represented in varying degrees in all light, irrespective of its source.

It must be remembered that the thermic effects of light are due to the impingement of the rays upon the translucent cutaneous tissues. The arrest of the light rays by the skin and subcutaneous structures produces radiant heat which has a higher penetrating power than convection heat as generated by a hot-water bag or poultice, for instance. It has been found that the thermic effects of light extend to a depth of two inches or more, while convection heat is principally exerted upon the surface. In comparing the therapeutic action of both it will be seen that the changes produced in the tissues by the former are much more pronounced. Thus if the body be exposed to an intense light, as in an electric light cabinet bath, the resulting hyperemia and elimination of waste products by the skin and kidneys (cellular nutrition) are much more pronounced than in a Turkish or Russian bath. The marked augmentation of the oxidation processes in the tissues is shown by the greater amount of carbon dioxid thrown off by the lungs and by the increase of solids in the urine. It is also claimed that the natural defences of the body (phagocytosis) are greatly promoted.

The actinic or chemical rays play an important part in phototherapy only when the light is concentrated upon a localized area as in the use of the arc lamp. Under these circumstances the actinic rays appear to enhance as well as modify the action of the thermic and luminous rays. Thus the ultra-violet radiations, which are actinic, have been shown to exert an anti-bacterial action as well as to promote local phagocytosis.

I am not unmindful of the fact that much of our knowledge is still in the theoretical stage, and for that reason have refrained from entering into the many details. I will, therefore, proceed now to the clinical aspects of this subject, dividing it into the general and local applications of phototherapy.

The general application of phototherapy consists practically in the use of the electric light bath, and since much of the benefit to be derived from this agent will depend upon the apparatus employed, I will first give a description of what has proven to me to be the most satisfactory type of cabinet.

An electric light cabinet should be constructed according to the following plan. The cabinet should be octagonal in shape, 4 ft. square by 5 ft. high; the lining should be of white blotter and not mirror surface; the source of light should come from 100 40-watt tungsten lamps, conveniently arranged, so that they will be under control from within by properly placed switches, one-half or full number of the lamps to be employed, as desired. The cabinet should be open at the top, not entirely, but partly so and it should have an air vent 3 inches in diameter in the center of the floor, over which is placed a low stool 18 inches high, upon which the subject is seated. (It has been found that a ventilated room is much more quickly and evenly heated artificially than one that is closed or sealed.) The further advantages of this construction are that a large volume of light with a minimum amount of heat is produced in the cabinet, that the emanations of noxious gases and odors from the human body are quickly carried off, that the degree of cutaneous hyperemia and diaphoresis is much more intense, and that the usual depression and other unpleasant symptoms are entirely obviated, as compared with the older form of closed cabinet.

Among the conditions in which the electric light bath has proved to be most serviceable are arteriosclerosis (hardening of the arteries), gouty and rheumatic conditions, Bright's disease, diabetes, obesity and acute catarrhal affections of the respiratory tract.

In the majority of cases of arteriosclerosis in the earlier stages I have advised the regular use of these baths with beneficial results, and I firmly believe that they have warded off more serious organic changes which otherwise frequently ensue.

The effects of the baths are:

1. To induce intense hyperemia or reddening of the skin and thus reduce the congestion of the deeper organs, which is frequently present.

2. To increase elimination by way of the lungs and skin. It has been found that during and following the bath the elimination of carbon dioxid is practically doubled, while the profuse perspiration produced carries away much toxic or poisonous material and in that way relieves the overtaxed kidneys. As it is generally accepted that toxemia plays an important part in the

causation of hardening of the arteries, the benefit to be derived from this method is readily apparent.

Rheumatic and Gouty Affections.—In late years it has been frequently pointed out that many conditions commonly termed rheumatic differ essentially from the acute type of the disease which is very probably of bacterial origin. On the other hand, there is abundant reason to believe that these chronic forms which have been grouped under the names of rheumatoid arthritis, rheumatic gout, osteo-arthritis, arthritis deformans, are the result of auto-intoxication and disturbances of metabolism. From what has been said above it will be readily understood that the marked effect of the electric light bath in increasing elimination will exert a beneficial influence upon the toxemia in these cases and therefore prove of material aid to other treatment. The distressing pains and stiffness in the joints are also greatly relieved as patients have frequently assured me. In chronic gout, which is more frequent in this country than is generally thought, the action of light baths is to augment the cutaneous or peripheral circulation and in that way favor the absorption of uratic or chalky deposits.

It may be asked why a Turkish or Russian bath will not do equally well in the conditions mentioned. My own experience has shown that the effect of the light bath is much more pronounced and prolonged.

Bright's Disease.—One of the chief aims in the treatment of Bright's disease is to lessen the work of the kidneys. The light bath will be found a better auxiliary measure for accomplishing this purpose than the usual hot pack or steam bath. As previously pointed out, notwithstanding the profuse sweating induced, the patient experiences no depression because of the stimulating effect of the light energy upon the peripheral nerves.

Diabetes.—The light baths are not adapted to every case of this disease, but particularly to patients who present a dry skin with various cutaneous eruptions, especially of an eczematous character. The best results are obtained where diabetes is attended with high blood pressure.

Obesity.—The heat penetration in an electric light bath, which as already mentioned extends to a depth of over two inches, stimu-

lates the oxidation processes in the fatty tissues and promotes their disintegration in cases of obesity. It will thus prove an excellent auxiliary to the customary treatment.

Acute Catarrhal Affections of the Respiratory Tract.—The writer has frequently had an opportunity to witness the beneficial effects of an electric light bath at the beginning of a cold in aborting it or greatly ameliorating its course. From personal experiences there can be no question of its superiority over the customary hot bath and diaphoretic (perspiration inducing) remedies.

LOCAL APPLICATION OF LIGHT.

In the local applications of light the following means are available:

1. The arc light, which is best employed by means of an ordinary marine searchlight, with its glass front window removed. The one I employ consumes 25 to 35 amperes of direct current at 40 volts, and projects the light in parallel rays by means of a 12-inch parabolic reflector, and has a light value of about 5,000 candlepower.

2. The high power incandescent lamp with a carbon or tungsten filament of 500 candlepower and provided with a dome reflector. The carbon filament uses 12 amperes at 110 volts, while the tungsten lamp consumes only 3 amperes at 110 volts. The former gives off more thermic rays, while the latter produces a greater amount of white light with a minimum amount of heat.

Without entering into detail regarding the physiological action of light when applied locally, it may be of interest to call attention to some of its main features.

As already mentioned in discussing the general applications of light, it constitutes a means of generating heat within the tissues down to a depth of two inches or more, while convective heat is far less penetrating. Moreover, besides the conversion of light rays into heat, we have to deal with the chemical actinic rays which also play a not unimportant part in phototherapy.

The sum total of these combined effects is as follows. There is an increased local activity, as manifested by a pronounced hyperemia and an augmented tissue oxidation and elimination. The effects of radiant energy, however, are not confined to the

site of application, but are so diffused that remote effects are produced in distant organs and nerve centers as a result of peripheral or cutaneous stimulation. It is easy to understand that the increased circulation, oxidation and elimination in the affected part will relieve congestion and promote absorption of exudates and deposits and the excretion of toxic materials. It has likewise been shown by physiological investigators that the heat production in the tissues increases phagocytosis and thus enhances the vital resistance.

The rapid relief of pain and local spasm experienced from light therapy is due in a great measure to the reduction of congestion and to tissue relaxation. In this connection it may be emphasized that these decided effects are brought about without the least risk to the patient, a statement which is not applicable unreservedly to other methods of treatment.

I shall now briefly discuss those conditions in which the local application of phototherapy in my experience has yielded the most satisfactory results. The employment of the parallel rays from a high power marine searchlight as described above, applied for 30 minutes to the spine at a distance of 10 feet, is one of the most effectual and lasting means of relieving many forms of spinal congestion.

In the acute stages of bronchitis or in pulmonary congestion from almost any cause, light applications to the chest afford a more prompt relief of chest pain and respiratory distress than any other measure with which I am familiar. In cases of chronic bronchitis marked benefit is obtained by prolonged daily applications of light to the front and back of the chest, continued until marked redness and tanning of the skin is produced.

To promote more speedy absorption in pleurisy I know of no better means than the daily use of phototherapy. In lobar and bronchial pneumonia its beneficial influence is manifested by marked relief of pain and dyspnea (shortness of breath) and an improvement in the general comfort of the patient; and in cases where resolution was delayed, it seemed to hasten this process.

I have frequently had occasion to resort to this treatment, using either the arc or 500 candlepower tungsten lamp, in cases of both acute and sub-acute inflammation of the gallbladder,

congestion of the liver and other abdominal viscera from chronic malaria, alcoholism and persistent intestinal auto-intoxication. It is no exaggeration to say that my results have been far better than when sole reliance was placed upon customary medicinal treatment.

In the treatment of muscular rheumatism, neuritis and even the intense discomfort associated with herpes zoster (shingles). more rapid and lasting relief, due to diminished congestion and nerve sensibility, will be obtained by this method than by recourse to the various analgesics and with no risk of undesirable after-effects.

The pain in acute middle ear catarrh (common earache), the frontal or orbital headache accompanying acute colds, and especially involvement of the frontal sinus and ethmoid cells is promptly alleviated by a thorough application at frequent intervals of light from a 50 candlepower carbon or tungsten lamp in a suitable reflector. To this I can testify not only from my own experience, but I could add the testimony of many physicians familiar with the use of this potent therapeutic agent. In chronic ear trouble and disease of the frontal sinus and antrum, it has proved a very valuable auxiliary by relieving the congestion and clearing up the discharge.

It has been my privilege to witness the success of this treatment in several cases of catarrhal appendicitis, and it has seemed to me that the pain and other symptoms were more quickly ameliorated and the necessity of surgical intervention more often avoided than had been my previous experience.

In various types of septic conditions, such as phlebitis, so-called milk-leg, following child-birth, or intrapelvic operations, the use of light in the manner indicated or by means of the multiple light dome, as employed in the Women's Hospital in New York, has proved a well-nigh indispensable agent in gynecological practise.

It will be found equally useful in the treatment of infected wounds of the extremities, cellulitis, furuncles, varicose ulcers, and localized infective processes in general.

From experience up to date there seems to be a brilliant future

for this measure in hastening repair in cases of delayed union of fractures.

In an article published some time ago I reported observations which showed that it might be possible to prevent the occasional deleterious effects of the X-ray by following its application with the rays from a marine searchlight. It is very gratifying to me to state that subsequent experience has seemed to confirm these results.

If, in this rather fragmentary sketch, I have been sufficiently fortunate to impress upon you the value of phototherapy as a safe and efficient auxiliary in the treatment of many conditions, the object of this paper will be fully realized.

DISCUSSION.

PROF. F. C. CALDWELL: It is certainly desirable for us as illuminating engineers to know something about the curative effects of light. It seems, however, that our relation to a paper of this sort is rather a peculiar one, in that it is something that we know little about and are in no position to discuss. It would be a matter of interest to know to what extent the statements that are here made represent the consensus of opinion of the medical profession and to what extent they are the observations and views of only the author. It seems that if the contents of this paper are of the former class they are of great interest to us from an educative standpoint. If, however, the paper is of a controversial nature, we really are in no position to handle it.

MR. JOHN B. TAYLOR: The statements in the paper of Dr. Titus are unaccompanied by the data usually required by engineers or physicists to justify opinions respecting the correctness of the author's claims. The illuminating engineer, unless he is also a doctor of medicine, has neither opportunity nor right to attempt to check the results reported. The engineer should, therefore, keep an open mind and request further and more specific facts. Until these are available it seems proper to express the opinion that much is "not demonstrated."

There is plenty of physical evidence that X-rays and ultraviolet light affect the body tissue and kill bacteria. Is there similar evidence for the statement which appears three times, to

the effect that "* * * the thermic effects of light extend to a depth of two inches"? We may recall that the body tissue is largely water and that water cells are regularly used for the purpose of cutting off the infra-red or so-called "thermic rays."

Dr. P. W. Cobb: In the paper Dr. Titus lays stress on the fact which Mr. Taylor has just mentioned, *viz.,* the thermic effects of light extend to a depth of two inches or more. Now, the use of heat in the treatment of disease is, as you all know, a very old matter. Every mother of a family knows the value of it. But the means chiefly employed have been means which involve conduction, as examples, the hot water bag and the poultice. In more advanced therapeutics a hot air bath has been used, where, for instance, a joint which is suffering from some chronic trouble, may be baked, wrapped in cotton and placed in a chamber which is heated by a lamp. The results of this treatment have been very good in certain cases. The point that Dr. Titus wishes to make here is that the light rays penetrate to a greater depth than the heat that we can introduce into the tissues by any conduction or convection method. In using a light source such as a tungsten filament lamp for this purpose, there is a certain limit. We know that the infra-red radiation beyond the visible—barring a short interval just beyond the red—is rapidly absorbed by water. There would be then a certain amount of the energy which would be stopped at the very surface, or at very shallow depths in the skin. If the energy used were increased superficial burning would be the result. It has occurred to me that there is opportunity for scientific investigation which might materially augment the resources of the photo-theapist. It would seem possible that by investigation of living tissues the elevation of temperature at various depths might be determined and that, further, it would be possible to find just which wave-lengths are superficially absorbed and which ones penetrate the tissues deeply. Knowing these facts, it would be possible to make screens which would cut out the rays that are absorbed at the very surface by means of which the superficial heating effect could be avoided and a deeper heating effect obtained. We know, for instance, that in looking at the hand toward the sun, there is an orange reddish light that is transmitted through the thinner portions of the fingers. We

know that water will not transmit the longer-waved infra-red radiations. Could we so screen the light that only those rays which have a deep, penetrating power in the tissues would reach the skin and by greatly increasing the energy get intense deep effects without the superficial effect which might be undesirable? I want to put this in the form of a question to Dr. Titus and ask whether any scientific work has been done on the actual penetration of the rays into the living tissues, that is, with exact reference to their wave-length.

MR. G. H. STICKNEY: Dr. Titus points out what suggests an important application of light for the good of humanity. As most of us are untrained in medical practise, we are unable either to confirm or question his results. Even if only part of the benefits described could be assured of realization, it would seem to me that the subject would be well worthy of further investigation to the end that artificial light might be better adapted to meet such needs, and the facts of the case made more generally known.

MR. C. O. BOND: In one of the weeklies in the East, there appeared recently an editorial concerning the sun bath cures that were effected at some place in Switzerland, where high altitude and clear air gave an excess of ultra-violet light over what is obtained in lower altitudes and through different strata of filtering air. They are, it seems, accomplishing some quite remarkable results in cures of all sorts of diseases, so much so, that this editorial spoke with unbounded enthusiasm. If that be true, then it is quite worth while undertaking to duplicate these conditions by artificial light. But it would seem a difficult thing to do this where there is a glass bulb surrounding the source of light at the very beginning, because much of the ultra-violet radiation would be lost at that point. With the searchlight scheme which the author suggests, the glass face being removed, there is not the same chance of losing the ultra-violet rays.

DR. ELLICE M. ALGER (Communicated): I am not competent to discuss the technical side of Dr. Titus' paper, but there is one point I should make. The careless listener or reader might easily get the erroneous impression that photo-therapeutic apparatus was about all the equipment that the physician of the future would need. No doubt the author intended to lay special emphasis

on the very important qualification contained in the last sentence of his paper, *viz.*, "phototherapy is a safe and efficient *auxiliary*" but not a method of treatment in itself. To use it as the doctor advises in appendicitis or in earache would be criminal for a man who was not competent to exercise the nicest judgment as to the point where the case ceased to be medical and became surgical. It would be little better for a man to treat Bright's disease and diabetes knowing nothing of their nature or their danger signals but with the simple faith that his therapy is good for all diseases. Electro-therapeutics has been particularly handicapped in just this way. Its special danger has been that it can be made useful in many different branches of medicine, of all of which no one human brain could have more than a smattering. It can be used safely only by one who has a sound fundamental training and who knows not only his own limitations but the limitations of his medium. I am glad Dr. Titus so evidently had this in mind in his concluding sentence.

Dr. John Willard Travell (Communicated): In this paper the many useful ways in which light may be utilized to alleviate painful and diseased conditions of the human body have been set forth briefly and forcibly. The limited subject has held the speaker to a description of certain therapeutic uses of light without permitting him to describe other mehods of treatment, or to make comparison with other methods as to the degree of efficiency in securing results. It is like reading a page in Materia Medica in which the good qualities of a drug like digitalis are enumerated and the many conditions in which it might be used noted. But from such a brief perusal one must not conclude that it will act in all these many ways better than all other agencies.

It is my fortune to be familiar alike with the therapeutic uses of light and with Dr. Titus' method of using it in his practise, and I feel impelled to emphasize the fact that he uses light as an adjunct to other physical agencies and drugs, and not as a cure-all.

Mr. R. B. Ely: Physicians have come to the office of the central station I am connected with and asked for information about lamps of the kind described in this paper. The only lamp of this sort that I knew of was the "Lucudescent" lamp, which

is regulated by a rheostat. Its rays I believe are more toward the infra-red than toward the ultra-violet. A great many physicians have come and wanted to purchase any kind of a lamp, so long as it was a large source that they could use in some way, apparently regardless of the spectrum of the lamp.

Another question about the electric bath. A great many complain about the cost of the electric baths in residences and are endeavoring to reduce that cost, but it has been my experience that they would not install a tungsten lamp in place of a gem lamp in these baths. I would like to know whether both carbon and tungsten lamps are used for specific diseases or whether one lamp in such a cabinet would answer all purposes.

Mr. W. R. Mott: For the last four years, the use of flame carbons has been coming forward in the treatment of disease. For this purpose there are used a blue flame carbon and the snow white flame carbon which is used for general illumination.

There is a book on the medical use of light, entitled, "Light and Energy" by Dr. Margaret A. Cleaves. I don't consider this a particularly important book at the present moment, but it summarizes an enormous fund of information. One thing that illustrates its defects is that it suggests the use of calcium peroxid in a flame carbon. Out of curiosity I tried it and had an interesting result. With about 20 per cent. of calcium peroxid the carbon did not give any important amount of light. With about 40 per cent., the carbon, after burning nearly five minutes, exploded due to dissociation of the calcium peroxid in the entire length of the electrode.

In regard to the use of the white flame arc, it is of interest to know that the candlepower increases nearly as the square of the current. The exponent is about 1.8 for some direct current open arc lamps. The white flame arc is much more powerful than any other known agent for actinic effect.

In the treatment of disease by light, there are two chief functions: one the stimulation of healthy growth, and the other the destruction of germs. In the destruction of germs the ultra-violet light is very strong. The best wave-length for each bacteria is not known.

A physician in Cleveland went to the laboratory of the National

Carbon Company to find out how to reflect ultra-violet light. That is not a simple proposition. In a book by Landolt and Bornstein, some data are given on the reflecting power of several materials. At a wave-length of $305\mu\mu$ in ultra-violet the reflecting power is:

Metal	Reflecting power in per cent.
Alloy (69 per cent. Al, 31 per cent. Mg)	72.2
Nickel plated	44.2
Copper	25.3
Platinum	39.8
Gold	31.8
Silver	9.1

Silver in the red has a reflecting power of about 90 per cent. One of the problems in the design of a lamp for therapeutic purposes is to reflect those rays which are required. In some cases the ultra-violet rays are wanted in others they are not.

The open flame arc gives off fumes which are objectionable and should be removed by good ventilation. I have found in the use of the white flame arc for the photographic studio, that a small piece of ammonium carbonate placed in the enclosed chamber will eliminate the bad effects of the nitric acid produced by all open arcs.

I have tried an experiment with the snow white flame carbons and found that glass of an ordinary window pane (0.08 in. thick), destroyed at least 50 per cent. of the photographic power, and with another chemical I found that a greater portion, as much as two-thirds, of the light was destroyed. The question of specially designed glass therefore, is important. If ultra-violet rays were required then quartz would be necessary. If stimulation were desired then other glasses specially selected for each treatment would be advisable.

Dr. E. C. Titus (In reply): The great majority of physicians do not themselves employ light in the treatment of disease, but do refer patients frequently to institutions where it and other physical agencies are in use.

The researches of Finger of Vienna demonstrated that by applying on ointment consisting of 4 per cent. esculin in glycerin, (the active principle of horse chestnut) to the skin that 80 per

cent. of the ultra-violet rays penetrate to the deeper tissues where ordinarily said rays are arrested by the skin.

The researches of Finsen of Copenhagen seem to prove that both the ultra-violet and the luminous rays exercise their characteristic influence not alone upon the surface of the skin, but also on the deeper parts as evidenced by their inhibitory action upon both local and deep tubercular processes.

Further, Kellogg of Battle Creek, Mich., the originator of the electric light bath cabinet, has shown that the processes of elimination of deleterious substances retained in the tissues are promptly intensified through the increased activity of the skin and of the kidneys, with elimination of waste products, and the doubling in quantity of the carbon dioxid eliminated by the lungs, as the result of the constitutional effects of the intense luminous rays upon the surface of the body.

One fact which Dr. Cobb seemed to lose sight of is that the body fluid is practically a circulating saline solution whose conductivity for light energy is one of the best known. Photographic plates have been affected by light through two or more inches of living tissue. In accordance with the law of conservation of energy, the luminous rays which are carried into the tissues are there converted into heat, inducing a physiological hyperemia and tissue oxidation or more active metabolism.

In connection with Mr. Mott's remarks it would seem proper to emphasize that the ultra-violet rays are used principally for local effects on the skin and superficial conditions, as for the dissipation of so-called port wine marks.

The writer had attempted to show the therapeutic applications of the full spectrum or more particularly of the luminous rays as an efficient auxiliary in the treatment of many painful and other disease conditions.

Referring to Mr. Ely's remarks,—it is the diffused and intense light energy employed in a cabinet bath, properly ventilated as pointed out in the paper, to which we attribute its chief therapeutic efficiency.

THE APPLICATION OF THE NEW HIGH-EFFICIENCY TUNGSTEN LAMP TO PHOTOGRAPHY.*

BY M. LUCKIESH.

Synopsis: The results of a general study of the photographic value of the radiation from the new gas-filled tungsten lamp are presented. A comparison has been made of this new lamp with the mercury-vapor lamp and the older type of tungsten lamps. The effect of voltage on actinicity has been studied. A scheme which has been developed for reducing glare from this lamp when used in portrait photography is described. Other photographic data are given. The fundamental principles of the lighting of studios are dwelt upon and the application of the tungsten lamp to various branches of photography are briefly described. Data on present practise in moving picture production studios are given and desirable accessories are shown.

The recent great increase in the efficiency of tungsten lamps of large size, brought about by introducing the filament in an inert gas, has made it possible for the new lamps to invade fields in which the incandescent lamp heretofore has not been an important factor. One of the interesting new fields in which the gas-filled tungsten lamp is meeting with considerable success is that of photography. Owing to the higher operating temperature of the filament the luminous efficiency is considerably increased and the actinic value of the light for ordinary plates even in a greater ratio. The natural characteristics of the tungsten lamp, such as portability, steadiness, ease of operation, unvarying quality, continuous character of spectrum, and high efficiency, are valuable allies to the most essential characteristic, namely, radiant energy of high actinic value. A study of the actinicity of the light from gas-filled tungsten lamps has shown that this lamp is destined to become an important factor in photographic procedure.

Sensibility of Ordinary Photographic Plates.—In ordinary photography only the rays of wave-length from 0.30 μ to 0.50 μ are of appreciable importance. In fact the ultra-violet radiation in daylight practically ends at 0.30 μ, the rays of shorter wave-

* A paper read at a meeting of the New York Section of the Illuminating Engineering Society, January 14, 1915.

length being absorbed before reaching the earth. Ordinary clear glass begins to absorb ultra-violet rays at 0.35 μ and becomes opaque for rays of shorter wave-length than 0.30 μ. Optical systems used in photographic apparatus usually being made of glass, the radiation of shorter wave-length than 0.30 μ is of no interest. Ordinary plates highly sensitive only to 0.50 μ can be made relatively more sensitive to rays of longer wave-length, but this procedure usually results in greatly decreasing the speed so that ordinary plates are far from orthochromatic. In ordinary portraiture there is no urgent need for plates sensitive to all the

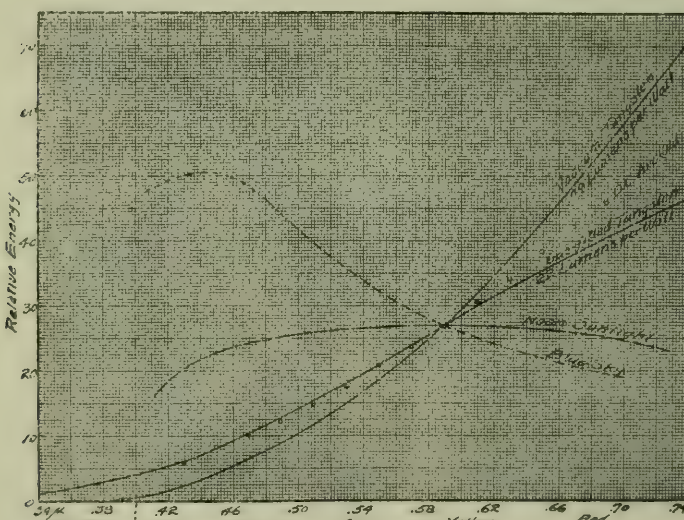

Fig. 1.—Spectral energy distribution in radiation from various sources.

visible rays because quite satisfactory modeling of the subject can be done in light and shade.

Spectra of Common Light Sources.—In Fig. 1 are shown the spectral distributions of energy in the spectra of the light from tungsten lamps as compared with skylight and noon sunlight. These are plotted with equality at 0.59 μ which indicates the relative values of energy of various wave-lengths for approximately the same integral values of luminous intensity. No spectro-photometric data on the latest arc lamps are available. The spectrum of the mercury arc, being a line spectrum, is not

plotted; but its actinic value for ordinary plates is much more nearly equal to that of daylight than that of the new tungsten lamp. In some other respects, however, it is not as desirable as the latter for photographic purposes. It is seen that the new high efficiency tungsten lamps emit relatively much more of the so-called actinic rays than the vacuum type.

Sensibilities of the Eye and Ordinary Photographic Plate.—In Fig. 2 are shown diagrammatically the spectral sensibilities of the eye and of the ordinary photographic plate for rays of equal energy value. While it is a well-known fact among those acquainted with the science of photography that the sensibilities of the eye and the ordinary photographic plate are far different, it is not so well known to many interested in the art of photog-

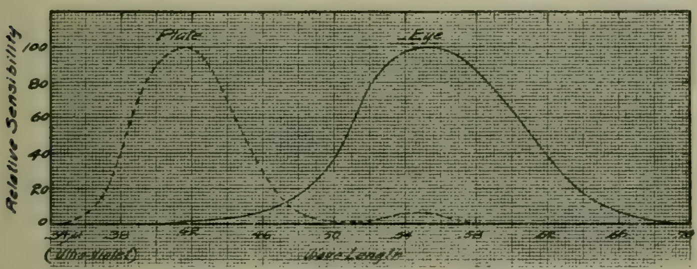

Fig. 2.—Spectral sensibilities of the eye and the ordinary photographic plate for rays of equal energy value.

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raphy. One of the aims of the investigator in the science of photography is to produce a high speed plate sensitive relatively to the various spectral rays in the same general manner as the eye. This has not yet been done. However, this is no great handicap in ordinary portraiture. On the other hand, such a plate would be invaluable in landscape and much indoor photography involving the reproduction of colored objects in true values.

Relative Actinicities of Mercury Arc and Tungsten Lamps.—In order to study the actinicity of an illuminant[1] it is advantageous to arrange an apparatus which will give a number of different values of illumination on the same plate simultaneously. This is easily done by means of a disk having openings of differ-

[1] Luckiesh, M., New Tungsten Lamps in Photography; *Electrical World*, July 19, 1914.

ent degrees. The disk used by the writer had ten openings varying in size from 10 deg. to 180 deg. The plate and disk were enclosed in a velvet-lined box with a small aperture in one end covered with ground opal glass which was chosen after finding that it transmitted practically the same rays that clear glass transmits and in the same relative proportions. This ground glass was necessary in order to obtain well-defined circular strips on the photographic plate, to obviate "pinhole" effects, and to cut down the light so that a reasonably long exposure could be given. Exposures should be sufficiently long so that they can be accurately timed with a stop-watch. In a given case both the exposure of the plate and the illumination on the disk were kept constant. Several plates were exposed for each illuminant with the usual unexposed "fog-strip" on each. These were developed under the same conditions and finally measured for transparency by means of a Martens polarization photometer. In order to interpret the data the following definitions are presented:

$$\text{Transparency} = T = \frac{\text{light transmitted}}{\text{light incident}}$$

$$\text{Opacity} = O = \frac{1}{T}$$

$$\text{Density} = D = \log O = \log \frac{1}{T}.$$

In Fig. 3 are plotted the results obtained on a Seed 26 plate with a mercury-vapor tube and three tungsten lamps. The plate chosen is representative of the sensibility of common photographic plates. The densities plotted against the logarithms of the illuminations produce a curve which is straight over a considerable region. This region is the accepted working range of the plate. Data of this character are so influenced by the conditions of exposure, development, kind of plate, etc., that no more than a general idea of the relative actinicities can be gained without presenting too extensive data for a paper of this character. It is seen that for an ordinary photographic plate the light from a mercury arc is three to four times more actinic than the light from the gas-filled tungsten lamp operating at 20 lumens per watt. Owing to the compactness of the light source of the tungsten lamp, however, the light is more efficiently controlled or

directed than in the case of an extended source. This tends to overcome the disadvantage of the gas-filled tungsten lamp with its lower actinic value per lumen.

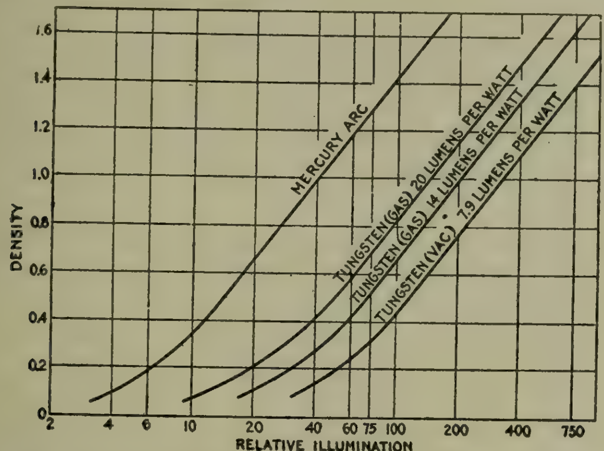


Fig. 3.—Relative actinicities of different illuminants for an ordinary photographic plate (Seed 26).

Effect of Voltage on Actinicity of Tungsten Light.—The influence of voltage or filament temperature on the actinic value of the light from the gas-filled tungsten lamp is shown in Fig. 4.

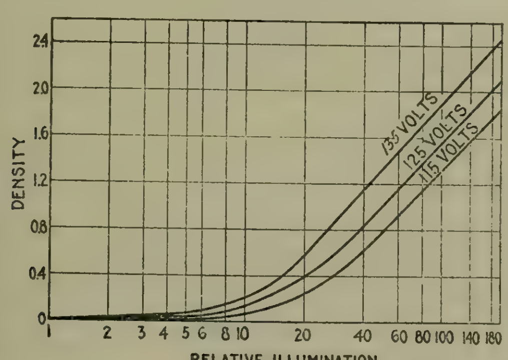


Fig. 4.—Effect of voltage on the actinic intensity of a 1,000-watt, 115-volt, nitrogen-filled tungsten lamp for an ordinary photographic plate (Seed 30).

A 1,000-watt gas-filled tungsten lamp operating normally at 115 volts and 18 lumens per watt was operated at three voltages and the relative actinicities of the light determined for an ordinary

photographic plate (Seed 30). It is seen that the actinic value increases very greatly as the voltage is increased above normal. For instance, to produce a photographic density of unity (transparency 10 per cent.), the relative amounts of radiation were 68 and 34 respectively for normal voltage (115) and 135 volts. Thus it is seen that an increase of 17 per cent. in voltage above normal doubles the actinicity of the light from this lamp for the plate used. In this experiment the illumination was allowed to increase with the voltage; that is, the position of the lamp was the same for the three voltages.

Effect of Voltage on Actinicity per Unit of Light Flux.—In order to show the influence of voltage on actinic value per lumen of visible light, another experiment was performed in which the

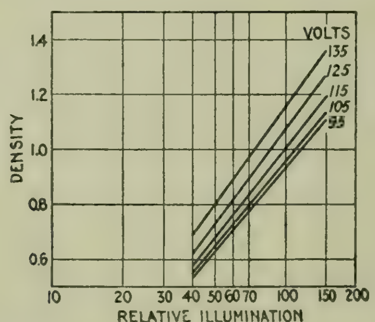


Fig. 5.—Effect of voltage variation on the actinicity of the radiation from a 1,000-watt, 115-volt, nitrogen-filled tungsten lamp; luminous intensity constant.

illumination falling on the multi-sector disk was kept constant. The results are shown in Fig. 5. This shows that the radiation affecting ordinary photographic plates increases more rapidly with voltage than does the total luminous radiation. The figures at the right represent different voltages. In this case a Seed 26 plate and the same lamp (1,000-watt, 115-volt gas-filled) as in the foregoing experiment were used. It is well to note that actinicity depends upon the sensibility of the plate under consideration. For instance if a plate is more sensitive to the violet or blue rays the actinicity of the radiation from a tungsten lamp will increase more rapidly than the luminous intensity with increasing voltage. However, the actinicity of this radiation for a

truly orthochromatic plate will increase in the same ratio as the luminous intensity. In other words, an increase of 17 per cent. in voltage would not double the actinic value for an orthochromatic plate, but would increase it only 67 per cent. It should be noted that the data represented in a given curve in Fig. 5 are for constant illumination as measured with a direct comparison photometer. It is thus seen in Figs. 4 and 5 that a great gain in actinic value can be obtained by increasing the voltage above normal. This led to an early trial of the scheme and there are outfits on the market employing this principle. An increase in voltage, however, results in a decrease in the life of a tungsten lamp; so that the writer was led to another method of producing light of high actinic value which could further be used where lamps were burned for long periods such as in taking moving pictures. The method which also has other advantages will be discussed later.

Orthochromatic Photography.—There are some kinds of photographic work (relatively few, however) that require an accurate reproduction of color values in light and shade such as in the photography of paintings and the tri-color printing process. Here orthochromatic plates are necessary and also a light source emitting all the visible rays. There are no truly orthochromatic plates on the market and where accurate work is desirable a very accurate filter is necessary to alter the spectral character of the light which reaches the plate so that the sensibility of the plate approaches closely to that of the eye. Most of the so-called orthochromatic plates available are far from being truly orthochromatic. Some are not even sensitive to red rays to an appreciable extent. Many show a relatively insensitive region at about 0.50 μ.

The high-efficiency gas-filled tungsten lamp is quite satisfactory for most of the work in orthochromatic photography. Its light has all the visible rays, which is quite essential. Owing to the preponderance of yellow, orange and red rays, it is unnecessary to use such a slow filter with this light as with daylight for most so-called orthochromatic plates. This means a somewhat higher speed for rough orthochromatic work than with daylight. However, for an orthochromatic plate such as the Cramer spectrum plate it will be found that there is too much of the radiation in

the long-wave visible region in the light of a gas-filled tungsten lamp. In other words this plate has been over-sensitized to the orange and red rays, which condition, however, is rare. As already stated the need for orthochromatic plates in the portrait studio is not urgent.

Adapting the Tungsten Lamp to Portrait Photography.—Owing to the fact that light from the gas-filled tungsten lamp is only one third to one fourth as actinic as daylight, it is to be expected that a condition of glare is liable to obtain in portrait photography[2] where a reasonably high speed is desirable. Such has been found to be the case. It is quite desirable to have sufficient actinic value per lumen of light in order to permit lenses to be used at the smaller apertures and yet to insure sufficient speed. The lamp, of course, can be burned above normal voltage for the brief period of exposure in portrait work. However, this procedure calls for special apparatus and introduces an undesirable flash-light effect. Further, it may have an appreciable effect upon the life of the lamp, although this is at present an unknown quantity to the writer. Certainly any appreciable amount of burning at a voltage sufficiently excessive to warrant the use of special apparatus would seriously decrease the life of the lamp. For continuous work such as the making of moving pictures, the lamps cannot be operated at any great increase above normal voltage without a very considerable decrease in the life of the lamp. The low actinic value of the light with a consequent condition of glare when sufficient illumination is used to gain high speed cannot be overcome by the use of diffusing screens.

It early occurred to the writer that some selective method was necessary to adapt the new tungsten lamps in the best manner to portrait photography. Experiments were made to produce a glass of such transmission characteristics that practically all the rays to which ordinary plates were sensitive would be transmitted while the non-photographic but highly luminous rays would be reduced. It was also necessary that the glass be quite transparent to infra-red rays, because too much energy absorbed by the bulb would be liable to cause serious trouble. Reference to Fig. 2 shows that it should be possible to produce such a glass.

[2] Luckiesh, M., Adapting the Tungsten Lamp to Portrait Photography; *Electrical World*, November 14, 1914.

Of course a highly efficient glass must be as transparent to the ultra-violet rays as the clear glass of the camera optical system.[3] Such a glass was made with a transmission for the total visible light from the 1,000-watt, 115-volt, nitrogen-filled tungsten lamp of about 30 per cent. while the actinic value was inappreciably affected for ordinary photography. A further aim was to reduce the ordinarily non-actinic rays in just the right proportions so that a pleasing light, apparently white in appearance, was obtained. A glass satisfactory in all these respects was obtained. It was found to transmit about 85 per cent. as much of the total radiation as clear glass, thus no trouble was to be expected from excessive local temperature. This glass must not be confused with the 'daylight' glass[4] recently developed by the writer. The two glasses are far different, for the daylight glass was developed for the purpose of altering only the visible rays of tungsten light to a spectral equality with daylight, whereas the glass here referred to has for its purpose the transmission of the ordinary photographic rays and the reduction of the remaining visible rays to such a degree that an *apparent* match with daylight is obtained.

The result of this development is a light that *appears* to be of the same color as daylight and a light of approximately the same actinic value per lumen. This means a great deal to the photographer. No accessory apparatus is necessary; merely a socket, lamp and reflecting apparatus. The light being practically of the same apparent color and actinicity as daylight it can be used to reinforce daylight. This has been done in many instances. When daylight fails it can be used satisfactorily alone with the same speed as daylight, thus the photographer does not need two different instincts for making exposures. Burning at normal efficiency, there is no danger from burn-outs, such as is present with excessive over-voltage apparatus, and the lamp can be used for such purposes as the production of moving picture films where long periods of continuous burning are necessary. It has proved successful in the latter field. The lamps have also been used suc-

[3] Luckiesh, M., Ultra-violet Radiation; *Electrical World*, June 15, 1915. Luckiesh, M., Glasses for Protecting the Eyes; TRANS. I. E. S., No. 5., 1914.

[4] Luckiesh, M., Artificial Daylight; *Electrical World*, September 19, 1914. Luckiesh and Cady, Artificial Daylight; TRANS. I. E. S., No. 8, 1914.

cessfully for home portraiture, and photographers have found them readily portable for indoor work outside of the studio.

Difference in Transparency of Blue Glasses for Ordinary Photographic Rays.—As will be seen from Fig. 2, the glass will be a bluish color; but in order to show that any ordinary blue glass will not be satisfactory the data in Fig. 6 are given. Out of a number of samples of glass the writer asked an assistant to choose two blue glasses. The assistant is somewhat trained in color-work and therefore understood clearly what 'blue' means. The two samples were exposed to the total light from the gas-filled lamp under the conditions previously described in the use of the multi-sector disk. The results show the great difference

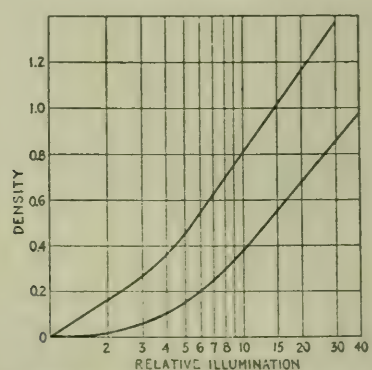


Fig. 6.—Relative actinicities of the radiation from a 1,000-watt, 115-volt, gas-filled, tungsten lamp after passing through two different specimens of blue glass. This illustrates that there is a great difference in the transparency of blue glasses for actinic rays. Ordinary plate used.

in the transparencies of the two samples for the so-called actinic rays. At a density of unity the radiation passing through one sample was about one third as actinic as the radiation which passed through the other. Experiments with other media also showed great differences in their transparencies to ordinary actinic rays. Many blue dyes were unsatisfactory owing to lack of permanency.

In order to show that the glass finally chosen for use in the bulbs of the gas-filled tungsten lamp for photographic purposes is highly transparent to the rays affecting ordinary plates, the spectra of the light from this lamp through two samples of the

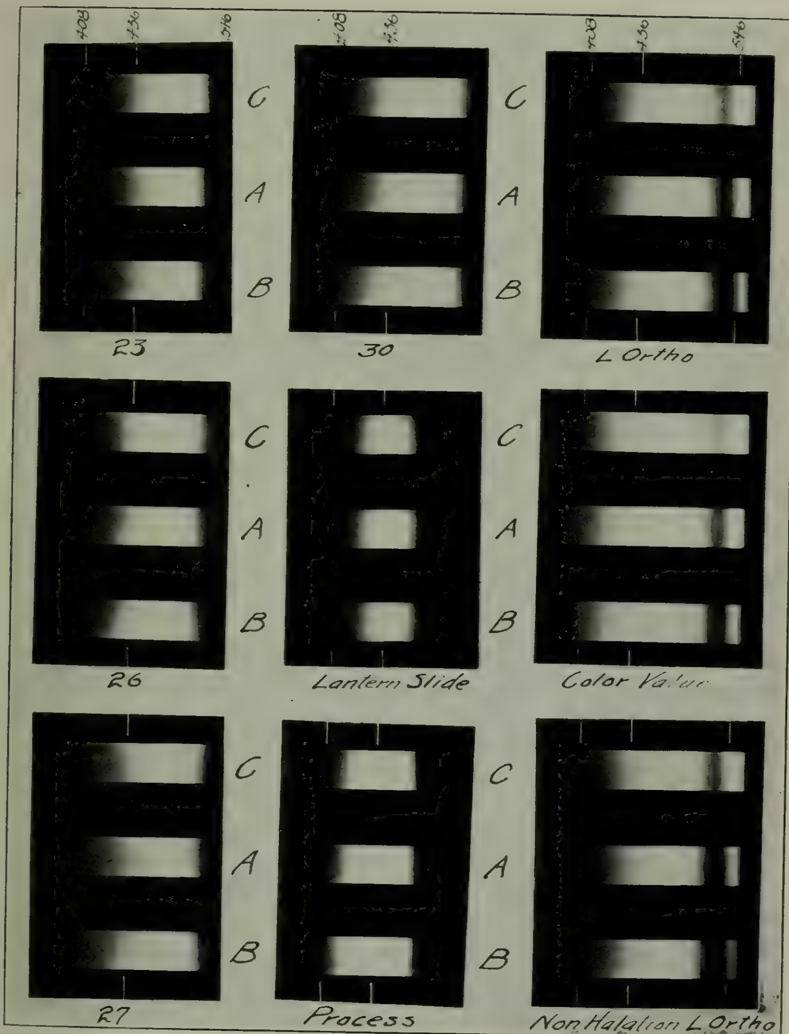


Fig. 7.—Effect of proposed glass on various Seed plates. C—clear glass. A and B—Samples of proposed glass transmitting 50 per cent. and 35 per cent. of total light from a tungsten-filament lamp operating at 18 lumens per watt.

Fig. 8. —A method of using the new high-efficiency special blue-bulb tungsten-filament lamp in a portrait studio.

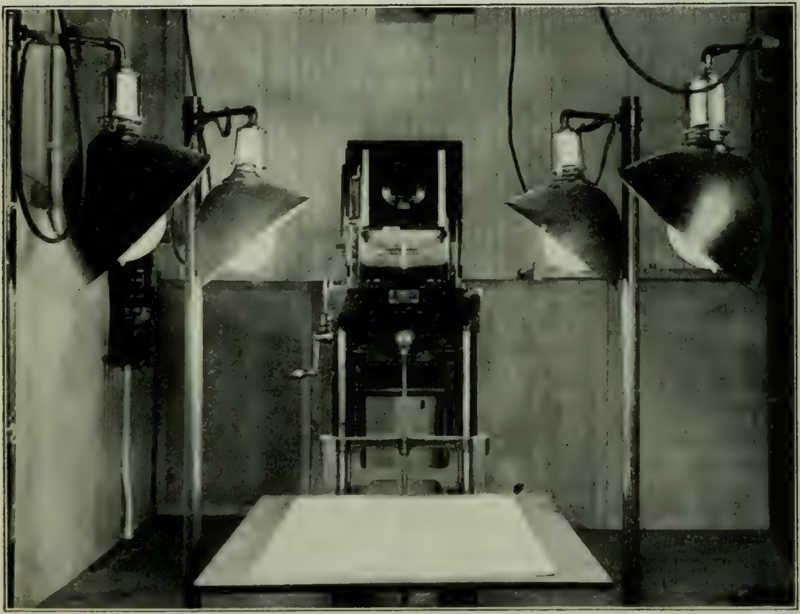


Fig. 9.—An example of photostat lighting. Four 1,000-watt, 115-volt, tungsten-filament lamps in white-enamelled, angle, steel reflectors.

proposed glass of different densities, as compared with the spectrum of the light through clear glass, are shown for six ordinary plates. It is seen in Fig. 7 that there is no visible reduction in the actinic rays for these first six plates on the left. To illustrate how insensitive ordinary plates are to the green and yellow rays attention is directed to the mercury-vapor comparison spectrum. The green ($0.546\ \mu$) and yellow lines ($0.577\ \mu$ and $0.579\ \mu$), to which 95 per cent. of the visible light must be credited, do not show on the reproductions which are made from ordinary plates. In some cases the green line shows very faintly on the plate. Here it is well to note that these spectograms were made with a prism spectrograph and owing to the much greater dispersion of the prism for the rays of short wave-length the plates seem to be more sensitive to rays at about $0.46\ \mu$. This is not the case, for they are most sensitive to rays close to the short-wave end of the visible spectrum.

It may occur to some that in the rare cases of orthochromatic photography a lamp equipped with a bulb or screen of this glass would be unsatisfactory. There is some reduction in speed in this case, but not an excessive amount as is shown for three so-called orthochromatic plates in Fig. 7. All the rays are yet present in this light after passing through the blue glass. There is really some advantage in many cases of orthochromatic photography in using the glass developed because the light after being altered by the blue glass screen is a rough approximation to daylight and therefore the same filters that have been used with daylight can be used with this light which would not be true with the unaltered light. Further it should be noted that the light from the gas-filled lamp after passing through the blue glass is just as actinic as daylight for any orthochromatic plate. In other words, there is produced a 'photographic daylight.'

Spectro-photography.—A note on the study of spectral sensibilities of plates may not be out of place. Owing to the variable dispersion of a prism, the rays of short wave-length are greatly weakened by the greater dispersion in this region than the rays of longer wave-length. The spectra of most artificial light sources are weakest in the ultra-violet region, which, combined with the weakening due to excessive dispersion, causes difficulty in obtain-

ing the spectral sensibilities of plates. A grating spectrograph is more desirable than one of the prism type, owing to the normal spectrum obtained. However, for some work the prism spectrograph can be made more satisfactory by allowing for the weakening due to dispersion by means of a screen or revolving disk. If the spectrum of a continuous light source of known spectral energy distribution be photographed on a plate and a positive be carefully made from this negative, the resulting positive can be placed in a proper position in front of the plates to be used and thereafter (provided they are the same plates) more satisfactory results will be obtained, owing to the elimination of the weakening due to excessive dispersion in the short-wave region. Another method of overcoming both the non-uniform spectral energy distribution and dispersion is found in making a templet in a revolving disk compensating for both of the foregoing with the result that the photographic effect for energy of each wave-length would be immediately that for equal amounts of energy throughout the whole spectrum. A screen which will compensate for either the variable dispersion or the non-uniform spectral energy distribution of the light source (or both) can be made by producing a cam of the proper character which when uniformly revolved would move a photographic plate across an image of a straight tungsten filament. The cam would cause the plate to move at just the proper non-uniform rate to cause a varying photographic effect on the plate of just the right amount at positions corresponding to the various wave-lengths so that the negative or positive, as the case may be, could be used as a screen for compensating the effects of non-uniform spectral energy distribution or variable dispersion or both. Possibly these schemes have already been applied. At any rate they are desirable aids where considerable spectro-photographic work is being done.

THE LIGHTING OF PORTRAIT STUDIOS.

It certainly would be presumptious for the lighting specialist to attempt to teach the portrait photographer how to light his subjects, for lighting is the basis of the photographer's art. The writer has often recommended that the lighting specialist consult the photographer and his product, for there is much to be gained from such a procedure. However, the lighting specialist can be

of assistance in the portrait studio because he has an acquaintance with the laws and methods for obtaining results desired by the photographer. In other words, the photographer knows the effects he desires, but the lighting specialist is perhaps better acquainted with the optical laws which govern the results.

The lighting of subjects in the portrait studio is practically entirely a matter of light and shade.[5] The character of shadows depends upon the position of the light source, the solid angle subtended by the source at the shadow-forming object, and the amount of scattered light reaching the object. The position of the light source determines the direction of the shadows, the area of the light source or more correctly the solid angle subtended by the light source at the point of interest, determines the character of the edge of the shadows, and the amount of scattered light determines the density of the shadows.

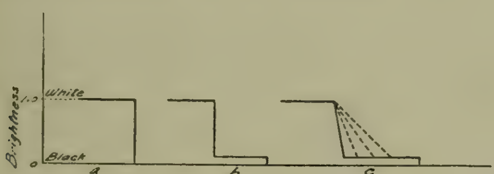


Fig. 10.—*a*—shadow produced by a point source of light amid non-reflecting surroundings; *b*—shadow produced by a point source of light and 10 per cent. scattered light; *c*—shadow produced by source of varying area and 10 per cent. scattered light.

Obviously a point source of light in a perfectly black room would produce black and sharp shadows on a diffusely reflecting surface. If the walls and surroundings were of such a reflecting power that 10 per cent. of the total light reaching the object is scattered light, a shadow on a diffusely reflecting surface would be one tenth as bright as the surface receiving the total light, but would yet remain sharp in outline. By varying the area of the light source the shadows would become less defined, but the 10 per cent. of scattered light is still effective. Some combination of these possible conditions is desired by the photographer.

The foregoing conditions are roughly represented in Fig. 10. The receiving surface is here assumed to be a perfect diffusely reflecting substance. The third case, *c*, is not an exact represen-

[5] Luckiesh, M., Light and Art; *Lighting Jour.*, March, 1913. Luckiesh, M., Light and Art; *American Gas Inst.*, October, 1913.

tation, for the sloping line would be more or less curved owing to the different distances of the elements of the surface of the light source from the shadow-producing point.

The lighting of a studio by means of a diffusely transmitting skylight is illustrated in Fig. 11. The skylight, *ef,* is for simplicity assumed to be vertical as is the case in many studios. Its shadow-producing qualities are dependent upon the solid angle, *epf,* (the dimension perpendicular to the plane of the paper can be assumed equal to the dimension shown for simplicity). Scattered light of course is controlled by screens and the direction of the shadows by curtains and the orientation of the subject. Often the amount of light passing through the skylight (the flux density) is insufficient to insure reasonably short exposures, so the

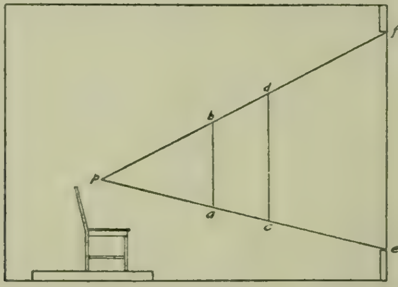


Fig. 11.—Illustrating the dependence of shadow-producing effect of extended sources upon the solid angle subtended at the subject by the source; that is, upon the size of the source and its distance from the subject.

subject must be moved closer to the skylight. This means that the solid angle is greatly increased with a result of apparent flattening in the photograph. In order to produce satisfactory modeling, a source too large in area is undesirable. This necessitates greatly reducing the skylight area by screens or moving the subject further from the skylight, both cases often resulting in an undesirable decrease in the illumination of the subject. Referring again to Fig. 11 it is seen that the light source can be decreased in area as the subject approaches it. Thus the shadow-producing qualities of the three sources *ab, cd,* and *ef* are the same, if the dimension perpendicular to the paper is assumed to vary in the same manner and the sources are uniformly bright.

A great advantage experienced in the use of artificial lighting

is that studios can be reduced very much in size owing to the greater amount of light obtainable per unit area of the source than in the case of the average skylight in cities and that the skylight can be dispensed with. Thus the skylight, *ef,* in Fig. 11 can be replaced by an artificial lighting outfit covered by a diffusing medium of much smaller actual size, *ab,* without altering the solid angle, *fpe,* and therefore without changing the shadow-producing effect.

Accessories for Tungsten Lamps.—The only essential accessories for tungsten lamps are a socket, a reflector, and a diffusing screen. In general angle reflectors such as those shown in Fig. 12 are found the most convenient. There are many standards already available of the same general character as shown in Fig. 13. These should be readily adjustable for height and portable. As

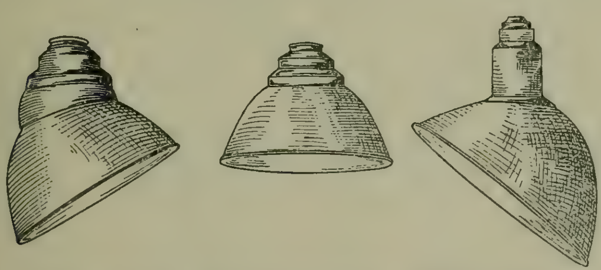


Fig. 12.—White enamelled steel reflectors suitable for photographic purposes.

would be expected, many photographers desire to carry out their own ideas as to apparatus for containing the lamps. This was one of the reasons for deciding to adapt the scheme of using the selectively transmitting colored glass, proposed and developed by the writer, to the lamp bulbs. Doubtless there are many cases where the glass could be used as a screen in front of the reflector, but the colored bulb presents a complete unit. This has been used behind various kinds of artificial "skylights" or windows. A satisfactory arrangement was found where a photographer had placed three of the special photographic lamps in an asbestos lined vertical box covered on one side with tracing paper. The middle lamp was hung somewhat lower than the others and the tracing cloth immediately in front of it was replaced by thin silk of less diffusing property with a result that a more directed effect

was obtained. Translucent and opaque screens were placed in various positions over the diffusing front depending upon the desired result. Some photographers have combined their special lamps with a mercury arc equipment already in their possession. Needless to say the ghastly appearance of the persons in the studio can thus be largely eliminated.

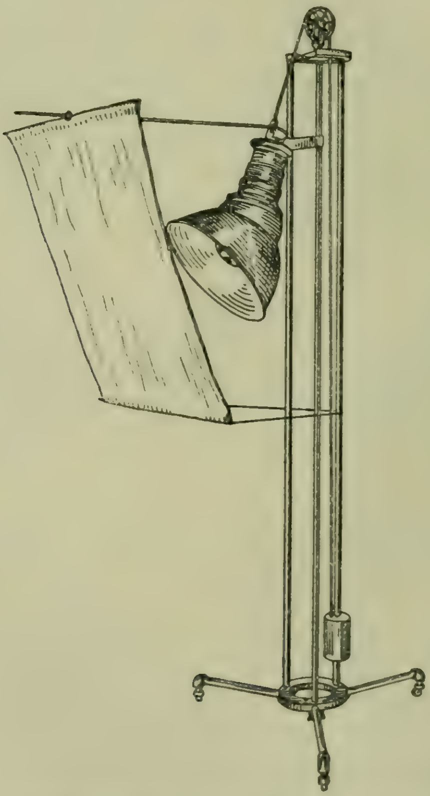


Fig. 13.—A standard for use with the gas-filled, 1,000-watt tungsten-filament lamp in portrait photography.

Here it might be well to bring to the attention of the photographer the practise of using the fluorescent reflectors with mercury arc lamps. This reflector is an excellent development, but the red and orange rays emitted by it, due to fluorescence, are obtained very largely at the expense of the ordinary actinic rays.

A more efficient scheme photographically would be to use the mercury arcs with white reflectors and eliminate the ghastly appearance of the persons in the room by the addition of tungsten lamps which would also contribute toward the actinic value of the total light. However, in general the writer would not recommend the use of a combination of two different kinds of illuminants where both are appreciably different in actinicity and color, owing to confusion which would result unless the light were well mixed by means of a diffusing screen.

In Fig. 8 is shown a photograph of a studio where two of the special photographic lamps are used in separate portable standards. Here it will be noted one unit is placed on each side of the front of the subject, but at quite different distances. Many photographers prefer to use the primary sources on one side of the subject, depending upon reflecting screens for lighting the opposite side sufficiently. The writer believes that in either case two units are desirable for satisfactory modeling and the majority of photographers with whom he has discussed the matter are of the same opinion. Of course the units can be placed behind the same diffusing screen, but the two sources seem to be necessary.

Regarding the speed at which portraits can be made with the special photographic lamp, it is sufficient to state that the exposures are the same as for daylight. This is not true with the clear lamp because it is impossible to obtain sufficient actinic value to insure success with short exposures without producing a condition of glare which is not conducive to the production of satisfactory pictures, unless excessive over-voltage is applied.

Printing and Enlarging.—The tungsten lamp has already played an important part in printing. The problem presents no difficulties and it is very easy to experiment with the lamps for this purpose. Here there is no need for the special blue-bulb photographic lamp, the purpose of which is to eliminate glare where human subjects are being photographed. The writer has seen many successful printing outfits employing various sizes of gas-filled tungsten lamps.

In enlarging, the new lamps find a newer field. Here there are two general forms of apparatus available; these are shown in Fig. 14. The upper illustration shows a satisfactory arrange-

ment for high speed. Where a condenser is used the light source should be compact. Concentrated-filament, gas-filled tungsten lamps have proven satisfactory for this purpose; the exposures being only a few seconds in duration. A cheap outfit is represented in the lower illustration. Here the lamp only is contained in a white enamelled reflector. Over the aperture a ground glass is placed and the negative is viewed against it. Owing to the greater loss of light due to the absence of a light-gathering condenser the exposures are many times greater than in the other case. However, satisfactory enlargements can be made in a reasonable length of time.

Of course the variations in the schemes for printing and

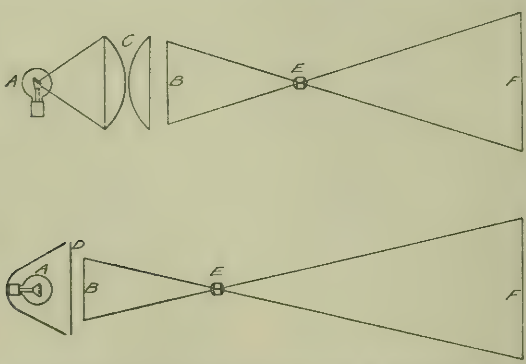


Fig. 14.—A—concentrated tungsten-filament lamp; B—negative; C—condensers; D—ground glass; E—lens; F—enlargement.

enlarging are manifold, so that it seems hardly worth while to do more than present the chief principles. However, a special field of interest is the lighting for photostats. This is best described by the illustration, Fig. 9. Here as many as four 1,000-watt, gas-filled tungsten lamps are used depending upon the size of the subject. Exposures of only a few seconds are necessary for satisfactory results.

Moving Picture Production Studios.—The lighting for moving picture production studios is a far different problem from that for ordinary portrait and commercial photography. In this field artificial light sources are excessively taxed in order to furnish sufficient actinic rays so that fully timed pictures can be

made in one sixty-fourth of a second. Pictures are made at the rate of sixteen per second, but considering the time during which the film is moving when the shutter is closed, and further allowing for the period during which the lens is not working at full aperture, the actual exposure is perhaps only one fourth as long as would be indicated by the rate of sixteen per second.

There appear to be two general classes of production studios. In one class the lighting is permanently installed in position and relatively large areas (approximately 18 ft. (5.48 m.) by 32 ft. (9.75 m.) are lighted. In the other general class the lighting apparatus is portable and relatively smaller scenes are usually lighted. Both classes are found combined in other studios. Doubtless both general schemes have their own advantages, but it appears to the writer after visiting a number of studios that the scheme of using portable lighting apparatus makes possible better effects in general and is the more economical in space, electrical energy, and equipment. Certainly better lighting effects can be obtained in many cases for the scenes are continually changing which demands a flexible lighting system in order to obtain the best possible effects. Possibly some producers find these advantages offset by the desirability of order.

In order to give an idea of the lighting requirements in moving picture production studios the following data on lighting equipment required in certain observed sets are presented.

I. Set about 16 ft. by 30 ft. (4.9 by 9.1 m.).
124 mercury-vapor tubes, d. c., 112 volts, 3.5 amperes.
Energy used, about 50 kw.
Lamps arranged in banks of 8 each.
Placed 48 overhead inclined at about 30 deg. from horizontal and 12 ft. (3.65 m.) from floor.
64 on one side in banks two tiers high.
12 at front 7 ft. (2.1 m.) above floor.
Actors worked to within 10 ft. (3 m.) from front lights.

II. Set about 16 ft. by 25 ft. (4.9 by 7.6 m.).
24 carbon arcs, a. c., 220 volts, 14 amperes.
Energy used, approximately 50 kw.
Placed 16 overhead and 8 in front about 8 ft. (2.4 m.) from floor.
Actors worked to within 10 ft. (3 m.) from front lights.

III. Set about 14 ft. by 20 ft. (4.3 by 6 m.).
18 carbon arcs, d. c., 110 volts, 20 amperes.
2 30-ampere carbon arcs in series for flood light through a window.
Energy used, approximately 43 kw.
Placed 12 in front and 6 on side near front from 4 to 7 ft. (1.2 to 2.1 m.) from floor.
Actors worked to within 5 ft. (1.5 m.) of front lights.

IV. Set about 15 ft. by 15 ft. (4.5 m.).
12 carbon arcs, d. c., 110 volts, 20 amperes.
Energy consumed, approximately 27 kw.
Placed in front overhead in two rows about 8 ft. and 9 ft. (2.4 and 2.7 m.) from floor.
Actors worked to within 7 ft. (2.1 m.) of front line of lamps.

V. Set about 12 ft. by 24 ft. (3.6 by 7.3 m.).
48 mercury arcs, d. c., 110 volts, 3.5 amperes.
2 carbon arcs, d. c., 110 volts, 28 amperes.
2 carbon arcs, d. c., 110 volts, 30 amperes.
3 quarts mercury arcs, d. c., 110 volts, 3.5 amperes.
The 3 quartz mercury arcs and 2 carbon arcs were in front and the 48 mercury arcs were distributed on one side with the exception of two banks of 8 each which were near the front on the other side. None overhead. The 2 30-ampere carbon arcs were on the side near the front and about 10 ft. (3 m.) from the floor. These gave a marked effect in the picture. This appeared to be an exceptionally intelligent attempt to obtain good lighting effects.
Energy consumed, about 33 kw.
Actors worked to within 7 ft. (2.1 m.) of front line of lamps.

IV. Set about 10 ft. by 10 ft. (3 m.).
11 1,000-watt gas-filled tungsten lamps, 110 volts.
Placed in front corners about 8 ft. (2.4 m.) from floor. More lamps on one side than the other.
Energy consumed, 11 kw.
Light well controlled by angle reflectors.
Actors worked to within 5 ft. (1.5 m.) of front line connecting the lamps.

VII. Set about 10 ft. by 15 ft. (3 by 4.5 m.).
16 1,000-watt special blue-bulb, gas-filled tungsten lamps, 110 volts.
Placed 8 in front, 6 on side near front, 2 overhead.
Energy consumed, 16 kw.
Actors worked to within 7 ft. (2.1 m.) of front.

Of course the wattage necessary depends upon the actinic value of the illuminant used and especially upon the area of the scene.

The preceding data will be useful in estimating the magnitude of an installation, the area and character of the scene being known. There appears no field where the lighting expert is more needed. Notwithstanding the fact that a large number of units are necessary in order to obtain sufficient illumination of high actinicity for making moving pictures a great deal of light was observed to be lost by lack of attention to light-controlling accessories. The tungsten lamp can successfully be used in moving picture production studios, but care should be exercised in conserving the light for use on the scene. This lamp, owing to its compactness, readily lends itself to a high utilization efficiency which must be realized in order to insure success owing to the lower actinicity of this light. The necessity of the use of such a selective method of reducing the glare from these lamps by absorbing a portion of the non-actinic rays is emphasized in the moving picture production studio. The illumination necessary is enormous and if multiplied several times (as is the case when the clear tungsten lamp is used) becomes very annoying especially in the large sets.

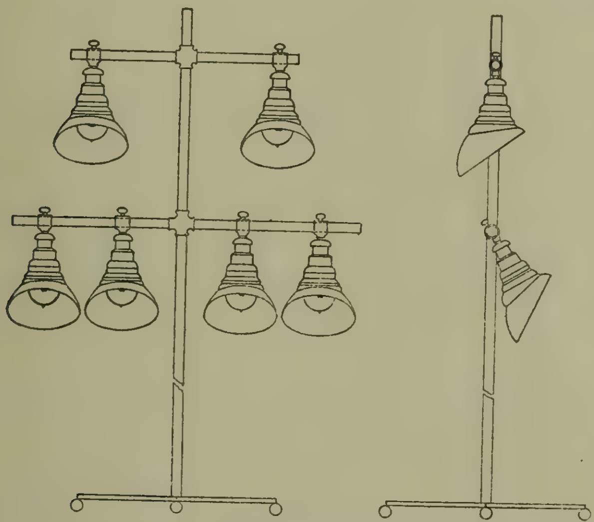


Fig. 15.—A method of supporting tungsten-filament lamps in moving picture production studios.

As already mentioned portability of the lighting apparatus is

quite desirable. The mercury arcs are usually arranged in vertical banks of eight each in a frame supported on wheels. The carbon arc lamps are usually non-portable with the exception of the bare high-amperage arcs which are placed on tripods. A form of portable standard developed in one of the studios using the special blue-bulb gas-filled tungsten lamps is shown in Fig. 15. The stand is made to be adjustable for height and the lamps may be tilted about their supporting arms. One of the white-enamelled angle steel reflectors shown in Fig. 12 was adopted and found satisfactory. It has also been recommended in one studio using the scheme of permanent installation that the blue-bulb gas-filled tungsten lamps be used in series with a rheostat which would reduce the voltage of the lamps below normal. Only while the camera is being operated would the rheostat be cut out, thus subjecting the lamps to about 10 per cent. over-voltage. This would reduce the number of lamps necessary and if care were exercised the decrease in life of the lamp would not be serious.

To summarize the requirements in artificial lighting of moving picture production studios, the characteristics of the light sources placed in their order of importance are as follows: high actinic value of the radiation, portability, control of the light, color-value of the light, energy consumption. In most cases energy consumption was found to be a minor consideration.

The author desires to acknowledge his indebtedness to Mr. H. McMullan for his assistance in the experimental work and for the preparation of the illustrations.

DISCUSSION.

Mr. Wm. A. D. Evans (Communicated): There are one or two points brought out in Mr. Luckiesh's article which are not entirely clear to me, and there are also two or three items, regarding which I am not in entire accord with his views.

On the second page Mr. Luckiesh makes the following statement:

> The spectrum of the mercury arc, being a line spectrum, is not plotted, but its actinic value for ordinary plates is much more nearly that of daylight than that of the new tungsten lamp. In some respects, it is not as desirable as the latter for photographic purposes.

I cannot conceive in any respect whatsoever that the mercury-vapor lamp is not as desirable as the nitrogen-filled lamps for photographic purposes. A lamp to be desirable for photographic purposes should be rich in the so-called "actinic rays." And as Mr. Luckiesh has stated that the actinic value of the spectrum of the mercury-vapor lamp is nearly equal to that of daylight, it would seem that its desirability for photographic purposes could not be added to.

On page 4, it is stated:

> It is seen that for an ordinary photographic plate the light from a mercury arc is three or four times more actinic than the light from the gas-filled tungsten lamp operating at 20 lumens per watt. Owing to the compactness of the light source of the tungsten lamp, however, the light is more efficiently controlled or directed than in the case of an extended source. This tends to overcome the disadvantage of the gas-filled tungsten lamp with its lower actinic value per lumen.

In relation to this, I note further on that Mr. Luckiesh states, on the fifth page, that "a 1,000-watt, gas filled tungsten lamp operating *normally* at 115 volts and 18 lumens per watt." Under ordinary operating conditions, is the nitrogen-lamp operated at 18 lumens per watt; whereas, in comparative tests against mercury arcs, is the lamp operated at 20 lumens per watt?

Regarding the "extended light source" I desire to say that the average photographer is accustomed to natural light coming from a skylight for his work, which is nothing more or less than an extended light source and the question of diffusion is most important for proper photography. As far as possible, photographers desire to get away altogether from the so-called "spot-lighting" effects. It might be advisable in some cases to use a spot-light to bring out certain high lights, etc., but the main lighting is always desired from an extended source. I fail to see how in this case the gas-filled lamps by being more efficiently controlled can overcome the disadvantage of its lower actinic value per lumen.

On page 13 the statement is made that:

> The green line (0.546 mu) and the yellow lines (0.577 and 0.579 mu) to which 95 per cent. of the visible light must be credited do not show on the reproductions which are made from ordinary plates.

From investigations made by Messrs. Fabry, Lardenburg, Von

Recklinghausen, Henri, Coblenz, and others showing the relative intensity of the four visible lines in the mercury spectrum, operating in a low pressure lamp or glass tube lamp, the green and yellow lines (0.546 mu and 0.577-9 mu) are responsible for practically 75 per cent. of the light in place of 95 per cent., as stated by Mr. Luckiesh.

In this connection, it might be stated that a very curious coincidence occurs in the mercury lamp. Of the four lines which are prominent in the visible spectrum, the line 546, which is present, is located at the point of maximum sensibility of the eye; while the line 404 is located approximately at the point of maximum sensibility for the photographic plate.

On page 12 Mr. Luckiesh shows a photograph of a photo-reproducing machine lighted by four 1,000-watt nitrogen lamps. In ordinary practise, throughout the country, this work has been accomplished by two 385-watt mercury-vapor lamps, which shows a ratio of approximately one to five in the amount of energy consumption for the same class of work.

On page 19 it is stated:

> Regarding the speed at which portraits can be made with the special photographic lamp, it is sufficient to state that the exposures are the same for daylight. This is not true with the clear lamp because it is impossible to obtain sufficient actinic value to insure success with short exposures without producing a condition of glare which is not conducive to the production of satisfactory pictures, unless excessive over-voltage is applied.

From reading this, it would see as if the author meant that with the blue glass lamp added actinic value was secured, that is, an ordinary clear lamp could have its actinic value increased simply by putting on the blue glass. I do not think he meant to convey this idea, but this is the impression which would be gathered.

In relation to the lighting of motion picture studios I desire to state that most of the data submitted by Mr. Luckiesh is for small work. For one of the largest indoor stages in the country the lighting installation consists of 17 banks of eight mercury lamps each, hung overhead and about 8 ft. from the floor at the front line and gradually rising at about on angle of 30 degrees, so that the back lamps are about 20 ft. from the floor. Two banks are placed in front, and the number gradually widening

out going towards the back. Along one side are also hung five banks at an angle of about 45 degrees to throw the light in on the side. These lamps are all mounted overhead on trolleys, and can be moved lengthwise of the studio, so that the scene can be set up on any one of three stages. In addition, there are provided six floor stands of eight lamps each, which are used on one side of the stage and down towards the front, practically all the light coming from overhead and one side, there being, as might be said, a complete curtain of light across the ceiling and down on the side. This stage allows the setting up of scenes 32 ft. deep, with a back line of 24 ft., and a front line of 8 ft., and approximately with an average intensity of about 300 to 350 foot-candles.

Furthermore, with this mass of lamps lighted, there is practically no glare to bother the actors and the heat is in no way excessive and hardly noticeable.

In summarizing the requirements of the artificial lighting of motion picture studios, the author places the characteristics of light sources in the following order: the high actinic value of the illuminant, the portability and control of the light, the color value and the energy consumption. He states in most cases the energy consumption was found to be a minor consideration. This has not always been the writer's experience, as energy consumption is quite a vital fact in a large studio, which is being operated all day and is a point which has to be taken into consideration.

Moreover, another point which the author neglected to mention, and which is very important—that is the maintenance. This is a feature which I believe is as important in motion picture studio work, as in any other commercial industry.

Dr. C. E. K. Mees (Communicated): The advent of the new high-efficiency tungsten lamp was naturally of the very greatest importance to those interested in the development of photography, inasmuch as it not only placed at their disposal with artificial light a high-intensity source, but that source differed from the former high-intensity sources in the fact that it was especially rich in red and green rays.

The importance of this is derived from the fact that the tendency of photography is towards the effect of color correct

methods, and eventually of color photography. Whereas the older photographic materials were sensitive only to the shorter wave-lengths, within the last few years there have been introduced materials sensitive to the whole visible spectrum and radically different from the earlier orthochromatic plates, which were sensitive only to the blue and violet and to a small region of the yellow-green of the spectrum. These panchromatic plates are of comparatively recent introduction, and while they are largely used for special work requiring sensitiveness to red and green, such as color photography or commercial work involving the photography of red and yellow objects, their use in portraiture is rapidly increasing, though it is, at present, very limited, the professional photographer preferring to use the more easily manipulated and cheaper materials to which he has hitherto been accustomed. The advantages of panchromatic plates for portraiture, however, are manifest. The human skin is covered with small capillaries of a red color, producing streaks and blotches of light red, which, while nearly invisible to the eye, have a very strong absorption for violet light, so much so that under a light source which transmits no red the skin is seen to be of a very uneven texture, and this uneven texture is reproduced in photographs taken on materials sensitive only to the shorter wave-lengths, so that portrait negatives exaggerate skin defects, and invariably are worked up by hand in the retouching process.

Retouching is used partly to correct defects in lighting, and partly to enhance the beauty of the sitter, but the greater portion of the work done is to improve the surface of the skin, and it is this work which has caused retouching to be reproached with the spoiling of the likeness.

From this it will be seen that the use of panchromatic plates is by no means likely to be confined to the few kinds of photographic work where they have hitherto been considered essential, because there is, in fact, little photographic work where correct color rendering is not an advantage, and in portraiture, which represents the widest field of all, the advantage is so great that red sensitive plates would probably have been used long ago but for the difficulties which attend their use. Of these difficulties the greatest has been the greater exposure which has been neces-

sary in order to get correct color rendering. Even with the best color sensitizers, the sensitiveness to red and green which can be obtained is much less than its sensitiveness to blue light when tested on a daylight spectrum, and consequently in order to get satisfactory color rendering, yellow filters have to be used with the plate, which considerably increases the exposure.

It is not true that orthochromatic or panchromatic plates are much slower in their total sensitiveness than non-color sensitive plates, but even with the best panchromatic plates an increase of exposure of about three and a half times is necessary for daylight with the lightest filter which will give correct rendering, and this increasing exposure has greatly militated against the application of the plate to portraiture.

When we turn to the employment of artificial light sources, however, we are faced with quite different conditions. Artificial light sources are so rich in red and green rays that only a very light filter—if, indeed, a filter at all—is required for the use of panchromatic plates, while the multiplying factor of this filter is reduced by the excess of red and green in the light source, so that a panchromatic plate, with such a source of light as the nitrogen tungsten lamp, requires less exposure than the corresponding plate unsensitized, while, of course, the color rendering is quite satisfactory. The introduction of the nitrogen tungsten lamp, therefore, marks an era in artificial lighting for studio work as it does in almost all other branches of the lighting art.

With the introduction of this lamp photographers all over the world commenced experiments which were marked with great success, and there is no doubt that the nitrogen tungsten lamp is destined to be one of the chief illuminants for studio portraiture in the future, and indeed I, personally, am inclined to think that studios lighted in this manner will to some extent displace daylight studios. With the introduction of this illuminant the possibility of obtaining correct color rendering in color portraiture is very greatly increased, and although at first the tungsten lamps would be used with ordinary plates, the use of panchromatic plates will undoubtedly grow, and we may expect consequently that indirectly the tungsten lamp will aid in the production of

more correct portraiture, giving a more faithful rendering of the skin texture than has been possible in the past.

Turning to the new lamp of blue glass, this lamp, while undoubtedly of a pleasing color to the eye, abandons the very advantages of excess of red and green which are such valuable factors in the tungsten lamp when used with color sensitive materials, and it will, therefore, clearly not be of use for this purpose. At the same time, most studios do not and will not for some time use such color sensitive materials, and, therefore, the loss of the red and green in the blue glass lamp is of no importance photographically, and the loss of the blue light being small (though it is by no means negligible) the diminution of glare and the more pleasing color would entirely justify the adoption of the screen lamp.

The great advantage of this lamp is that it can be used to reinforce lighting either by daylight or by the enclosed arc where the unscreened lamp on account of its color would be objectionable as introducing two different colors in the lighting, and for this purpose the new lamp will undoubtedly be in considerable demand. Thus, it seems to me that both the unscreened and screened lamps represent an advance in photographic portraiture —a screened lamp as a reinforcing lamp for daylight, and an unscreened lamp as assisting the introduction of materials giving correct color reproduction—which must tend to the general improvement of the status of photography.

When we turn to cinematographic work, however, it seems a little doubtful whether tungsten lamps will be employed to the same extent for black and white cinematographic work, though they represent an invaluable aid in the experimental work on color cinematography, on which so much is being done. An investigation of the gradation of non-color sensitive materials such as those used for the negative film in moving picture work shows that the gradation improves as we pass towards the more infrangible end of the spectrum, so that a film which gives very excellent gradation at $400\mu\mu$, will give by no means as good results for a light with a mean wave-length of $480\mu\mu$, and if comparative photographs are taken by these two wave-lengths, it will be found that in the photograph taken by the longer wave-length the high-

lights are clogged up and deficient in detail and very easily show strong halation, while in the photograph taken by shorter wave-lengths the highlights will retain all their quality, and owing to the opacity of the film for light of this wave-length halation will be nearly absent. For this reason it is improbable that in cinematographic work the nitrogen tungsten lamp will displace the illuminants at present used; namely, the mercury-vapor lamp and the enclosed arc lamp.

If cinematographic pictures be taken by mercury-vapor lamps and also by nitrogen tungsten lamps, the difference in the quality of the pictures will be most marked, the highlight gradation being well retained in those taken by the mercury lamp and the absence of halation being noticeable, while in those taken by the nitrogen tungsten lamp the highlights are clogged up and halation appears wherever any portion of the picture has been over-exposed. This effect is undoubtedly due to the difference in the color of the two light sources. If the spectra of the two light sources be photographed by non-color sensitive materials, it will be seen that the center of action of the nitrogen tungsten lamp is at $480\mu\mu$, while a fair average of the lines of the mercury-vapor lamp would place its center of action at about 400, the lines at 365, 404 and 436 being all of nearly equal density.

A small practical advantage of the mercury-vapor lamp is that it is a light source of considerable area and of low visual intensity, so that the lamps can be used without any diffusing screen, and if long tubes are used widely spaced, a set of mercury-vapor lamps makes an effective substitute for a window.

When we turn to the question of efficiency, we also find that although the nitrogen tungsten lamp is of high efficiency for the visible spectrum, it is much surpassed by the mercury-vapor lamp and the enclosed arc lamp in the violet and ultra-violet regions of the spectrum, and this is an additional reason for the use of these latter lamps in moving picture studios, where efficiency is of high importance.

Summarizing the views expressed in this paper, therefore, we may say that in ideal photography materials should be used which will render color values as they are seen by the eye, and that the introduction of the nitrogen tungsten lamp renders the use

of such materials for studio work easy and is to be welcomed for this reason. For studio work where non-color sensitive materials are to be used, and especially where a light acts as a supplement to daylight, or the enclosed arc lamp is required, the blue glass nitrogen tungsten lamp will be of great use. For moving picture work, however, both conditions of efficiency and of the quality of the resulting negatives are likely to tend towards the continuance of the light sources at present in use, and to prevent their replacement to any appreciable extent by the nitrogen tungsten lamp.

PROF. GEORGE A. HOADLEY: Mr. Luckiesh has shown us in the curves on the third page (Fig. 2) the difference in sensitiveness, between the eye and the photographic plate. Now take a point source of light, and let a ray from it strike upon a lens, of which we may consider this a half cross-section. We know that when the ray strikes the lens, we have a bending of the ray. We also know that if it is white light when it strikes the

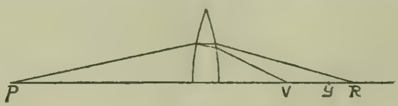


Fig. A.

lens, the ray will not only bend, but will be dispersed, and we shall probably have it coming down in this direction—we have the red at R (Fig. A) and the violet nearer the lens at V, and consequently we have a horizontal spectrum from the red to the violet—between those two points. Now this becomes of value when you consider that we shall have a red focus at R and a violet focus at V. The eye will focus better in the position marked Y; the photographic plate in position V. We have pretty nearly that condition in astronomical photography. We are looking at point sources in the location of thousands of stars, and if we focus our apparatus and put the plate at Y, we shall find that the time of exposure will have to be very much longer than if we should put the plate near V at the actinic focus. Consequently in a larger lens it is necessary to make that distinction, or that difference in the position of the plate, in order to take the picture more quickly, and in order to get a

better focus. With the ordinary camera lens that is not necessary at all perhaps on account of the fact that we get rid of the difference in focus by many different kinds of glass and a combination of lenses.

Mr. M. Luckiesh (Reply to Mr. Evans): In regard to Mr. Evans' first quotation from the second page of my paper will state that the actinic value of the mercury arc, while nearer to that of daylight for ordinary plate, need not be sufficient to stamp the mercury arc as good as tungsten light for all photographic work. Mr. Evans cannot conceive this so I will refer him to the proper rendering of color values as one instance where the mercury arc fails.

Mr. Evans next quotes from the fourth page of my paper regarding the operating efficiency of the tungsten lamps used. I designated in each experiment the efficiency at which the lamp was operating. I am merely interested in presenting facts. Further the efficiency of operation is subject to change from month to month as there is always the tendency toward higher luminous efficiency in the electric incandescent lamp industry. There is no point in the least to Mr. Evans remarks on that score. I used different lamps at different times and for the sake of exactness expressed the conditions exactly.

He further takes issue with my statement that the light from the small source (the incandescent filament) is more efficiently controlled than from an extended source. I believe Mr. Evans at any other time will agree to this. He misconstrues my meaning for I do not recommend spot light effects in the studio. His conception will be clearer when I remind him that in the moving picture studios is this exemplified. In a mercury arc installation much of the light is not directed upon the objects to be photographed but wanders away never to return.

He further quotes from the thirteenth page and takes issue with my statement that 95 per cent. of the light from the ordinary mercury arc which I used must be credited to green and yellow lines. He quotes others as obtaining different results. I must remind Mr. Evans that the problem of color photometry has not yet been solved, so various persons will obtain different results depending upon the method used. I quoted data ob-

tained by myself by the direct comparison method of photometry after considerable investigation of methods of color photometry.

I used as an illustration a photostat equipped with four 1,000-watt tungsten lamps and Mr. Evans states that the same work is done with two 385-watt mercury-vapor lamps. His citation lacks value, however, inasmuch as he neglects to give comparative speed. Various wattages are being used for such equipment, but I took this photograph merely as an illustration for high speed work. Mr. Evans appreciates that the necessary factor—exposure—has been omitted by him in his comparison.

Mr. Evans quotes from the nineteenth page and thinks that the impression gained is that the blue lamp adds actinic value. The portion of the paper devoted to the modified bulb is devoted practically entirely to data showing that I have eliminated rays of practically no photographic value for ordinary plates.

In regard to the lighting of moving picture studios by means of tungsten lamps I submitted only the data available at that time. I am sorry that I was only able to cite smaller studios, but the work has just begun. The outlook is promising and I will try to present much more data regarding this field at some future time.

Mr. M. Luckiesh (Reply to Dr. Mees): Regarding the future of the tungsten lamp in cinematographic work we can only conjecture. It is being used to-day in some of the smaller studios with entire satisfaction. Certainly it will find a place of more or less importance in such work. I quite agree with Dr. Mees that we should photograph with an object of rendering true color-values as they are seen by the eye. But at present this is being done only to a relatively small extent in the portrait studios. It was for this reason (and others) that I have recommended and developed the blue bulb lamp giving a rough "photographic daylight." Dr. Mees, however, shows that there are exceptions when he claims that the illuminants at present used in cinematographic work have an advantage over the clear tungsten lamp *because the light of longer wave-lengths* is present in lesser amounts in the former light sources.

SAFEGUARDING THE EYESIGHT OF SCHOOL CHILDREN.*

BY M. LUCKIESH.

Synopsis: The object of this paper is to present to school authorities the importance of proper lighting in safeguarding the eyesight of school children. Data are presented showing the increasing prevalence of near-sightedness with advancing school grades and other data showing the decrease in the percentage of shortsightedness accounted for in part at least to the improvement in lighting conditions. Opinions of authorities are quoted which show the importance of good lighting in preserving eyesight and the economic gain in such conservation. Factors which influence vision are discussed; namely, illumination, uniformity, direction of light, glare, character of reflecting surfaces, etc. Legislation on school lighting is discussed. Extracts from enacted laws pertaining to the subject and general recommendations for school lighting legislation are presented. Satisfactory and unsatisfactory conditions found in modern schools are illustrated and the co-operation of school authorities in improving lighting conditions is urged. A partial bibliography of the literature pertaining to school lighting is appended.

INTRODUCTION.

There are twenty million school children in the United States who are devoting several hours each day to study or performance of other work equally trying on the eyes. According to the available statistics about 10 per cent. of the number of school children examined are found to have defective vision. In many cases the percentage of defectives has been found to increase with increasing age. This increase can be attributed largely to the manner in which the eyes are used. Light being essential to vision, it is natural to turn to lighting for a possible cause of the increase in the number of children with defective vision. Considering those that are already defective it is certain that proper lighting and proper use of the eyes will result in a large number being permanently cured. Further, this is an age of prevention as well as cure. Prevention of defective eyesight means proper lighting and proper use of the eyes. It should be remembered that the child's eyes are immature in growth and function and therefore quite susceptible to misuse. Insufficient illumination whether due to shadows owing to improper direction of light or

* A paper read at a meeting of the Pittsburgh Section of the Illuminating Engineering Society, Cleveland, Ohio, January 29, 1915.

to an actual deficiency in the amount of light at a particular desk results in the tendency of the child to hold the reading matter too close to his eyes. Practising this continually, results in a malformation of the eye muscles and consequent near-sightedness. The tendency once begun requires more effort to correct than to prevent beforehand.

Glare from windows, blackboards, glazed paper or artificial light sources causes eye-fatigue with resulting disorders too complicated to discuss in a paper of this nature. A lack of training in avoiding such conditions also aids in increasing the number of children having defective vision.

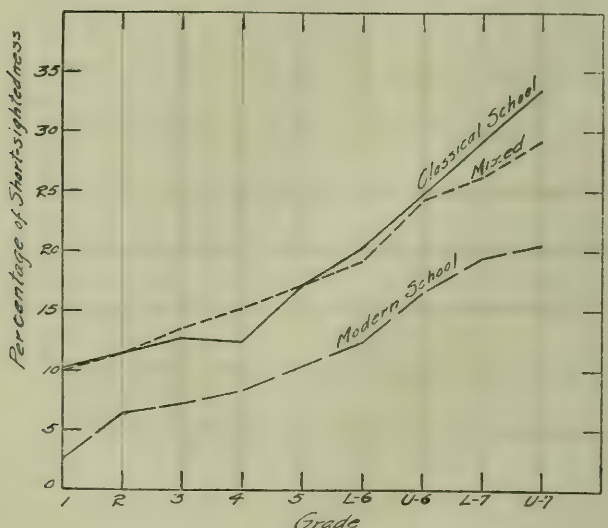


Fig. 1.—Prevalence of short-sightedness in three secondary schools in Stockholm, 1894-1903.

Prof. Johan Widmark of Sweden in a paper on "The Decrease of Short-sightedness in Secondary Schools for Boys in Sweden," presented at the Fourth International Congress on School Hygiene held in Buffalo in 1913, publishes some interesting statistics Some of these have been plotted and are shown in Figs. 1 and 2. In Fig. 1 are shown the data gathered in three kinds of schools. These illustrate the increase in near-sightedness with increasing grade of class. The classes are named first, second, third, fourth, fifth, lower sixth, upper sixth, lower seventh, and upper

seventh. The corresponding percentage of near-sighted pupils is shown for each class. The most striking feature is the unquestionable increase of near-sightedness from class to class. A further point of interest being the greater prevalence of near-sightedness in the "classical" school than in the "modern" school. Another school which has both the classical and modern side has in general a slightly less percentage of near-sighted pupils than found in the classical school.

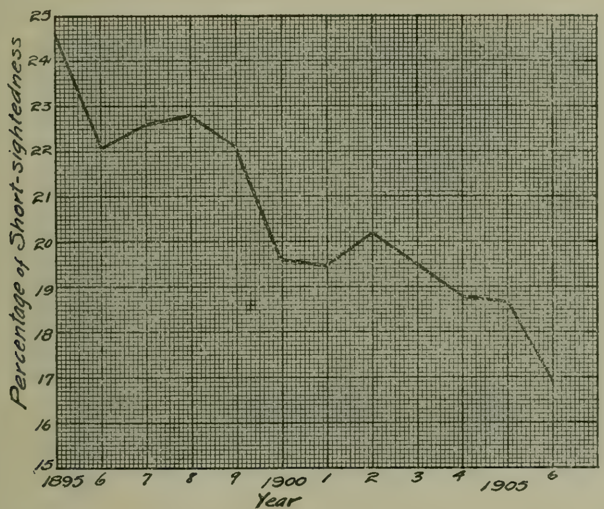


Fig. 2.—Percentage of short-sightedness in the highest class of all the state secondary schools for boys in Sweden.

In Fig. 2 is shown the steady decrease in the percentage of short-sightedness in the highest classes of all the state secondary schools for boys in Sweden from 1895 to 1906. Data obtained in 1883 but perhaps not directly comparable with the foregoing data showed a percentage of near-sightedness as high as 65 per cent. in some schools. Prof. Widmark accounts for the decrease in short-sightedness in recent years as illustrated in Fig. 2 as follows:

Among the hygienic improvements which have been effected during recent years in our schools and in all the conditions relating thereto I should be disposed to mention first the improvements in the lighting of rooms and in the printing of the books used by pupils, and that for this reason among others, that the influence of these changes is of effect in

the homes too, the strain on the eyes when the pupils are busy with the preparation of lessons being thereby much reduced. If the comparison is made between the methods of lighting rooms now and those of ten years ago, the difference is very striking, both at school and at home.

He further comments upon the significance of the decreased use of the old Gothic types.

Opinions of Other Authorities.—At the Buffalo meeting on School Hygiene conservation of vision received marked attention as is illustrated by the following abstracts:

D. P. MacMillan, director of child study in the public schools of Chicago, states:

Defects of the senses of sight and hearing, to which appeal is largely made in school room activities, are considered by some to be the primary causes of delay or derangement of normal development, and they lead to the formation of injurious habits, etc.

W. H. Brainerd, an architect of Boston, states in discussing "The Ideal School Site":

The first purpose of the school is instruction. The first need of instruction rooms is light for the use of the eyes and apparatus. Light must be in abundance and without glare. Sunlight should reach all instruction rooms, and others as far as possible. Long continued hot sunlight is not desirable in class-rooms. The desirability of exposure for class-rooms is in the following order: easterly, southerly, westerly. For large buildings a site permitting of the major axis running northeast and southwest is most desirable. Class-rooms should have the easterly and southerly exposures; assembly halls and accessories westerly and northerly exposures.

Dr. F. Park Lewis of Buffalo in a paper on "Sight Saving and Brain Saving," states:

It is an accepted fact, recognized by ophthalmologists everywhere, that changes occur in the eyes of children during the period of their school life, of which the most prominent symptom is a steadily progressive development of near-sightedness. As definitely formulated by the late Prof. Dufour: (1) In all schools the number of short-sighted pupils increases from class to class. (2) The average degree of short-sightedness increases from class to class. (3) The number of short-sighted pupils increases with the increase in school demands.

Dr. James Kerr of London, states:

Ocular experience is the only final test of illumination. Eyestrain is due to fatigue due to overwork or glare. The eye adapts itself to brightness by varying its sensitiveness. Primary glare is due to physical effects on the retina, secondary glare to difficulty in adaptation. One third of our school children have such defective visual acuity that better illumination is necessary than for normal eyes.

He further states that

> Artificial lighting for each school place should not be less than 2 foot-candles. Blackboards require 60 per cent. more. Glare must be guarded against.

Dr. Lewis C. Wessels of the Bureau of Health, Philadelphia, in speaking of defective vision from the economic standpoint states:

> In Philadelphia each pupil costs about $35 per year to teach. Under normal conditions a pupil 14 years of age should reach the eighth grade at a cost to the state of $280. If on account of defective vision the child only reaches the fourth grade in that time it has still cost the state $280, but with only $140 worth of result, a loss to the State of $140. The loss to the child is considerably more because at the age of 14 it is likely to be put to work, poorly equipped, its earning power curtailed for want of a proper education so that it can contribute but little toward its own support or that of the state. So again the state loses.

He further explains how the Department of Public Health through a division of ophthalmology furnishes glasses free to poor children and adds

> We are now refracting nearly 2,500 cases a year. If we save each one of these children but one year during its entire school life there will be an annual saving of over $87,000 not counting the child's time and increased efficiency.

This is certainly an interesting phase of the subject. A further discussion of the economics of the relative costs of prevention and cure would also be of interest.

These are opinions and statistics from only a few authorities but probably sufficient to rout any lurking suspicion that the safeguarding of eyesight is not a vital problem. Further it is seen that the light expert has a great deal in common with school authorities, medical examiners, and architects in safeguarding the most important and educative sense—vision.

FACTORS INFLUENCING VISION.

Illumination.—The eye is a very flexible organ and can adapt itself to a tremendous range of brightness. Visual acuity or the ability to distinguish fine detail depends upon the illumination, although above a certain minimum value of illumination acuity increases very slowly with increasing illumination. One sees by distinguishing differences in brightness and color. In ordinary reading brightness contrast makes it possible to distinguish the

black letters or words on the lighter background. After a certain minimum value of illumination is reached the process of distinguishing ordinary type becomes increasingly difficult with decreasing illumination. The amount of illumination necessary for reading with comfort depends upon a number of conditions, but under fairly satisfactory conditions the illumination at the top of any desk should not be less than 2.5 foot-candles. This minimum value should be greater for daylight than for artificial lighting because of the greater non-uniformity of the illumination under average natural lighting conditions indoors.

Uniformity.—A fair degree of uniformity of illumination on the plane of the desk tops is quite desirable owing to the strain on the eyes resulting from the necessity of adapting the eyes for considerable variations in brightness where there is too great non-uniformity. Owing to architectural difficulties it is quite impossible to obtain uniform illumination with natural light. The diversity, however, can be reduced even in this case to a satisfactory value. Satisfactory uniformity is easily attainable in artificial lighting.

Direction of Light.—One of the fundamental principles of proper lighting is to have light come from the left. This of course assumes that all persons are right-handed. In natural lighting three systems are in vogue, unilateral, bilateral and sky-lighting. The predominant opinion favors unilateral lighting with the windows on the left of the pupils when seated.

In artificial lighting there are three general systems of lighting, the so-called direct, semi-indirect, and indirect lighting. These divisions are not clearly defined. The first system in which most of the light is directed downward by shades and reflectors is perhaps used more than the others although the semi-indirect method is growing in popularity in many places and is perhaps more generally satisfactory in the problems of lighting class rooms, reading rooms, etc. In this system the light source is contained in a translucent glass bowl open at the top. Some light passes through the bowl to the working plane, the remainder reaching the working plane indirectly by reflection, chiefly from the ceiling.

Glare.—In natural lighting the sky is the source of light

chiefly depended upon. Very elaborate studies of the amount of visible sky necessary at any point of the room have been made by reflection chiefly from the ceiling. Various authorities agree in general, notwithstanding the fact that the data have been gathered by different methods. The brightness of the light source whether natural or artificial, should be low, say not more than three candlepower per square inch. The brightest sky measured by the writer has shown 2.5 candlepower per square inch. One of the important effects of high brightness is the production of annoying after-images. In Fig. 3 are shown some results on the

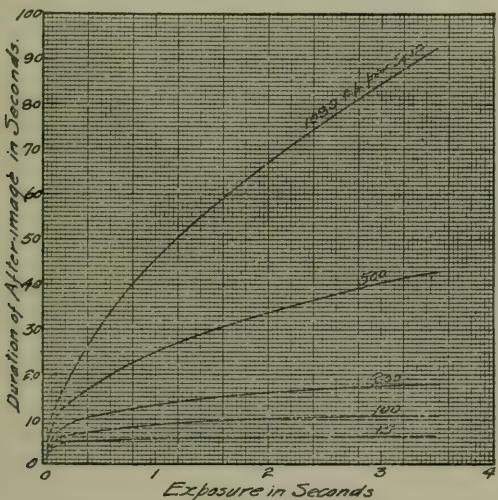


Fig. 3.—Effects of brightness of source and exposure on the duration of the after-image.

duration of after-images. The brightness of a tungsten filament operating at 7.9 lumens per watt (1.25 w. p. m. h. c.) was found to be 1,080 candlepower per square inch. In the same units the approximate brightnesses of a Welsbach mantle and a frosted tungsten lamp of the older type are respectively 30 and 5. These figures are given to aid in comprehending the data. The after-images actually lasted longer than shown in Fig. 3, but at the end of the intervals of times indicated they ceased to be annoying and changed color which latter served as a criterion in making the observations. It is seen that the after-images from

bare artificial light sources besides fatiguing and being harmful to the eye can be annoying owing to loss of time occasioned and dangerous when the person is working near machinery owing to the temporary blinding effect. Nevertheless inspection shows that bare lamps directly in the field of view are often found in the shops in technical schools where there is an ever-present danger from machinery in operation.

Intrinsic brightness is not alone the cause of glare. An area of sky when viewed through a window surrounded by relatively dark walls causes a very annoying glare yet the sky is perhaps no brighter than 1 candlepower per square inch. Thus excessive brightness contrasts are found to be responsible for the annoying, and sometimes very discomforting and harmful conditions of glare. This is shown by an easy experiment. Hold a lighted electric incandescent lamp before your eyes in an ordinary room and under most conditions you will experience uncomfortable glare. However, if you take the lighted lamp to the window and view it against the sky the glare is hardly noticeable. There is another factor which complicates the situation namely total light flux. More light is entering the eye in the latter case which possibly by the process of adaptation reduces the annoyance somewhat. It has become recognized, however, that brightness contrast plays a large part in eye-fatigue. A blackboard viewed in juxtaposition to a white wall often results in annoying glare.

Light surroundings such as walls and ceiling have a general tendency in reducing the conditions of glare. For instance a bright ceiling reduces the annoyance of an artificial light source viewed against it. Light walls reflect light back to the side of the room containing windows thus lessening the contrast between the bright sky and the adjacent walls. The colors of walls and ceilings usually found satisfactory are light tints of buff, yellow, or grey.

Artificial light sources should be hung high in order to be outside the normal visual field if possible. They should be screened with shades or reduced in brightness by enclosing glassware. Likewise windows should be equipped with approved shades in order to control the daylight as much as possible and, when necessary, to screen out the direct sunlight.

Polished surfaces are recognized as sources of annoying glare and in many cases defeat well laid plans of the lighting specialist. In Fig. 4 the various kinds of reflecting surfaces are illustrated; *a* shows mirror reflection, and *b* the reflection from a perfectly mat surface; *c* shows a combination of these which results from a highly glazed white surface, for example varnished white walls and glossy paper. A piece of polished window glass placed over white blotting paper is a simple illustration of this kind of reflection; *d* and *e* illustrate two other types of reflection encountered.

Obviously a child holding a mirror flat upon the printed page of a book can see the image of a light source which is well above

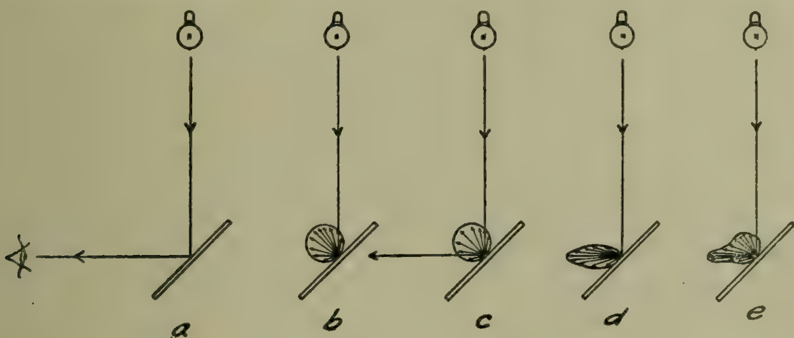


Fig. 4.—Various types of reflection.

his head out of the normal visual field. The result of glazed paper too often used in books is somewhat analogous. Owing to the fact that the image of the light source is regularly reflected by the black letters and white background with practically equal facility, there is a decrease in contrast between the printed matter and the background causing difficulty in reading and also a distracting and harmful effect of the "glare spot." For these reasons glazed surfaces have been condemned by the light specialist. Glare owing to regular reflection from blackboards is a common annoyance in school rooms. This can be overcome in various ways including tilting, the judicious use of window shades, and by lighting them artificially. The proper placing of blackboards can be determined beforehand as illustrated in Fig. 5; *a* shows a plan of a class room lighted from one side.

In this case the lighting is from the wrong side, but this was chosen because it represents an actual case. The paths of the rays of light can be followed in their course with the result that the condition shown is just what was observed in the room in question. In *b* is shown the elevation. In this case the window area was too small and a further mistake was made in placing a blackboard between the windows. These are conditions that can not be too severely condemned. In *c* is shown a remedy for badly lighted blackboards. Walls and desk tops should also be as free from glaze as practicable.

Considerable data have been obtained on the effect of glare in reducing visual acuity, much of which will be found in references cited in the bibliography. However, an interesting case is shown in Fig. 6 because it brings out various points of interest and also incriminates the sky in glare production. An acuity object was set up in the shade of a building as far from the building as possible. The day was clear and light reached the object from more than one half of the sky. No light from the sun reached the eye or test object or immediate surroundings directly or by regular reflection. The writer who made the observations wore no visor to shield the eyes. Only a slight sensation of glare was apparent before beginning the test. However, as soon as acuity observations were begun the glare became very evident and rapidly grew painful. Five readings were made first through clear correcting glasses (represented by the black dots). As quickly as possible the clear glasses were replaced by yellow-green glasses of about 50 per cent. transmission for the total light and five acuity readings were taken (represented by crosses). A decided decrease in discomfort was experienced when wearing the yellow-green glasses and as will be noted acuity is higher in this case notwithstanding the decrease in illumination was fully 50 per cent. These glasses were again replaced by clear glasses and five acuity readings were made. This procedure was continued as indicated in Fig. 6. The interval of time required to make five readings including the change of glasses was the same in each case (being three minutes), but the actual time of taking the individual readings was not noted. Here they are plotted at equal intervals. While the above procedure is rather complex and bears upon

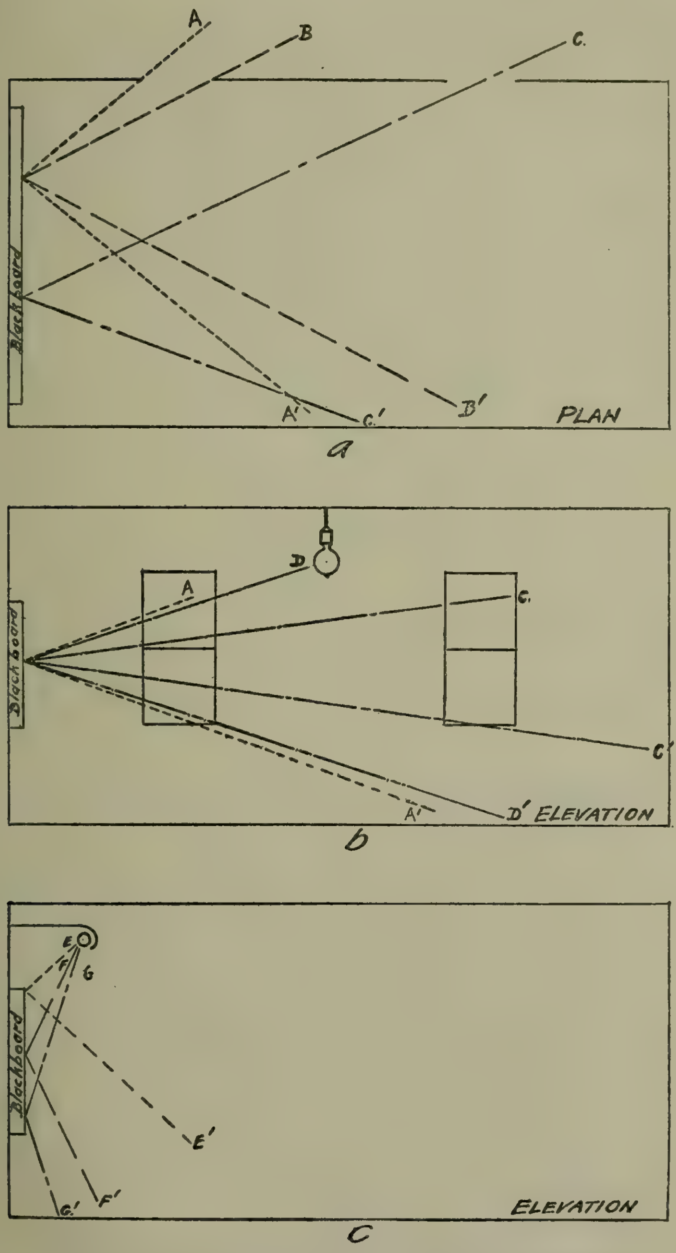


Fig. 5.—Showing law of regular reflection applied to blackboards.

problems worthy of much careful investigation, the experiment answered the intended purpose in bringing forth several points: (1) Glare conditions are not always apparent when the eyes are not engaged in serious work such as reading or distinguishing fine detail. However, bad lighting conditions are readily recognized when the eyes are called upon to do such work. (2) There is a rapid falling off of visual acuity when the conditions of glare are severe. (3) Such a harmless appearing light source as a wide expanse of sky can produce a very severe condition of glare. The intrinsic brightness is very low as compared with artificial sources, but the quantity of light is high and the image of the sky is spread over a large portion of the retina. (4) There was an apparent recuperation of the eye during the periods that the yellow-green

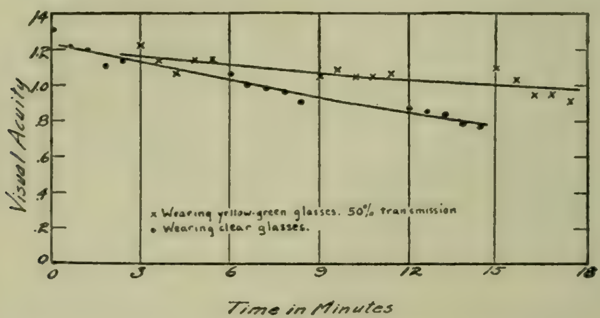


Fig. 6.—Showing rapid reduction in visual acuity under the glare from the unobstructed blue sky.

glasses were worn. (5) Notwithstanding the effect of glare, when clear glasses were worn, in reducing visual acuity the values of the latter when the colored glasses were worn remained considerably higher. (6) This experiment emphasizes the necessity of prolonging acuity readings over a considerable period if acuity is to be a criterion of the satisfactoriness of illumination conditions.

Some of the increase in visual acuity when the yellow-green glasses were being worn can be accounted for by the nearer approach to monochromatism of the light that passed through them. However, conditions indicated that the advantage was due very largely to a reduction in the glare. Other interesting conclusions can be drawn, but the illustration has already fulfilled its

object in bringing forth the facts that glare conditions are very complex and that cognizance of glare often depends upon the character of the activities in which the eyes are engaged.

LEGISLATION ON SCHOOL LIGHTING.

The legislation on this subject which has come under the observation of the author has been chiefly with reference to natural lighting. This is quite the expected course, but needless to say attention must be given to artificial lighting. The latter problem will be found much easier and no doubt will be officially taken care of eventually. It is the duty of this society and school authorities to urge proper legislation to cover lighting conditions completely. It may be interesting to quote extracts from codes already in existence.

Extracts from the Indiana "Sanitary School House Law" are as follows:

Interior walls and the ceiling shall be painted or tinted some neutral color, as grey, slate, buff or green.

All school rooms where pupils are seated for study shall be lighted from one side only, and the glass area shall be not less than one-sixth of the floor area, and the windows shall extend from not less than 4 feet from the floor to at least 1 foot from the ceiling, all windows to be provided with roller or adjustable shades of neutral color, as blue, gray, slate, buff, or green.

For left-handed pupils desks and seats may be placed so as to permit the light to fall over the right shoulder.

Blackboards shall be preferably of slate, but of whatever material, the color shall be dead black.

Abstract from the Rules and Regulations of the Indiana State Board of Health are as follows:

No class-room shall exceed 24 feet in width, with the ceiling not less than 12 feet nor more than 14 feet in height.

No window sash shall have more than four lights, and the tops of all windows shall be square. When the proximity of other buildings or a portion of the same building interferes with the proper lighting of a class-room, the light shall be properly projected and diffused by the use of prism glass.

When artificial lighting by means of electricity or gas is used the lights shall be placed near the ceiling and the lights deflected by proper shades toward the ceiling, either indirect or semi-indirect lighting being used.

Where the light in any class-room is from the north, the proportion of glass area to floor area should not be less than 1 to 5.

Architects, etc., shall certify by affidavit indorsed on all plans and specifications submitted that such plans and specifications comply with the Indiana Sanitary Schoolhouse Law and with the rules of the Indiana State Board of Health.

Abstracts from the Ohio State Building Code referring to school buildings are as follows:

The height of all rooms, except toilet, play, and recreation rooms, shall be not less than one half of the average width of the room, and in no case less than 10 feet high.

The proportion of glass surface in each class, study, recitation high school room, and laboratory shall be not less than 1 square foot of glass to each 5 square feet of floor area.

Windows shall be placed at the rear or the left and rear of the pupils when seated.

Tops of windows, except in libraries, museums, and art galleries, shall not be placed more than 8 inches below the minimum ceiling height.

The unit of measurement for the width of properly lighted rooms, when lighted from one side only, shall be the height of the window head above the floor.

The width of all class and recitation rooms, when lighted from one side only, shall never exceed two and one half times this unit, measured at right angles to the source of light.

The candlepower of electric lamps shall not be less than the following, viz.:

Auditorium	1 candlepower to 2½ sq. ft. of floor area
Gymnasium	1 candlepower to 2½ sq. ft. of floor area
Stairways and hall...........	1 candlepower to 4 sq. ft. of floor area
Class and recitation rooms....	1 candlepower to 2 sq. ft. of floor area

Enclosed fireproof stairways, service stairways, corridors, passageways, and toilet rooms shall be lighted by artificial light and said lights shall be kept burning when the building is occupied after dark.

The Illuminating Engineering Society is taking up the matter of the lighting of schools chiefly through a recently appointed Committee on School Lighting. Observations have been made and data have been collected for several years previous to the appointment so that fairly definite activities were begun at once. The following brief resumé of requirements in school lighting was presented to the Committee on Lighting Legislation for use as a basis in formulating a code on school lighting. This is not in complete form, but is expected to serve as a starting-point.

GENERAL CONSIDERATION.

The lighting of a school building should be referred to a competent expert before the plans for the building are drawn. The

importance of doing this early is evidenced by the fact that the orientation of the building plays an important part in the design of those features which depend for their satisfactoriness upon proper lighting.

Minimum intensity of illumination, 2.5 to 3.0 foot-candles on the plane of the desk top.

Polished surfaces such as blackboards, glossy paper, polished desk tops, and glazed walls should be avoided.

Light sources (sky or artificial) should be well out of the ordinary visual field.

Glare from blackboards should be avoided. This can be done by carefully placing them, by lighting artificially, by tilting them, and by keeping their surfaces mat. They should never be placed between windows.

Excessive brightness contrasts should be avoided. A bright source should not be viewed against a dark background. The walls adjacent to a blackboard should not be too light in color.

Surroundings such as walls and ceilings should in general be light in color. Ceilings and frieze should be practically white (high reflecting power). Walls should be reasonably light. Colors used should be white, grey, or tints of buff, cream or olive green.

Children should be taught how to safeguard their vision; that is, how to hold their books, to assume a correct position relative to the light source, to complain of glare from blackboards, etc.

Teachers should be instructed to teach these fundamentals to the children.

Good lighting should be incorporated in every course where practicable and especially in the "home-making" course.

MORE SPECIFIC RECOMMENDATIONS.

Natural Lighting.—Window area should be ample—that is, an appreciable percentage (say at least 20 per cent.) of the floor area.

The windows should preferably be located on one side of the room to the left of the students.

A portion of the sky should be visible from every desk top, at least 5 degrees vertically.

The width of the room should not be more than twice the window height.

The windows should be equipped with approved window shades for controlling the light and excluding direct sunlight.

Prism glass should be used in extreme conditions at least.

Lighting and ventilating courts should be painted white.

Minimum illumination on desk top, 3 foot-candles.

Diversity of illumination not greater than 100 to 1.

Artificial Lighting.—Ample general lighting is recommended. Local units subject to control of pupils are condemned.

Minimum illumination on desk top, 2.5 foot-candles.

Light sources should be out of normal visual field if possible. They should be equipped with diffusing glassware to reduce their brightness and screen the source from the pupils' eyes.

Highest permissible brightness, 3 candlepower per square inch when viewed against a light background.

Blackboards should be lighted by properly screened and judiciously placed local units.

The system of lighting will depend upon many conditions. Any well-designed system is satisfactory in its proper place. There appears to be a growing tendency for the semi-indirect system. It appears more generally satisfactory for class rooms, reading rooms, etc. In the shops a direct system is advisable.

No local units should be used unless absolutely necessary.

CONDITIONS FOUND IN MODERN SCHOOLS.

There is a large amount of authoritative data available pertaining to the best practise in natural and artificial lighting. References to many sources of valuable information are given in the bibliography. The practises which the writer considers best are already presented in a general manner throughout the paper. Specific recommendations apply only to specific conditions, so it is quite outside the scope of this paper to go into detail. It will be enlightening, however, to consider some actual conditions—good and bad—found in modern schools. It is gratifying to be able to state that some of the cases of faulty lighting shown here are being corrected. In general natural lighting conditions do not appear as bad in the modern schools which the writer has

had an opportunity to visit as the artificial lighting conditions although there are opportunities for improving the former.

In Figs. 7 to 12 inclusive are found some very faulty artificial lighting installations. The first general criticism is found in the use of the local unit subject to the control of the pupil. The average pupil knows practically nothing regarding the proper use of light. In the drafting rooms pupils were found working in the shadow of the hand or T-square when a slight adjustment of the lamp in front of him would have given him satisfactory lighting were it not for his neighbors' lamps which glared at him from all sides. In Fig. 7 the units are fastened to the drawing table. In this one respect this condition was more favorable than the case shown in Fig. 8 where the units were practically uncontrollable for they hung on drop-cords from a ceiling perhaps 12 feet in height with angle reflectors which could not protect the eyes of the individual without causing a bad condition of glare for many of his neighbors. The conditions were photographed as found on entering the rooms. Much more could be said against such practise, but the photographs speak for themselves.

In Fig. 9 is found the condition in a machine shop in a technical high school. The complexity of shafting and belts make it difficult to light this room by a system of general lighting. An attempt has been made and yet it could be done more successfully. If sufficient light cannot be directed to the lathes from overhead units, local units could be used as a last resort. But these should be shielded from all eyes by narrow concentrating reflectors instead of being left bare as shown in Fig. 10.

In Fig. 11 is seen a condition not unusual in the shops of the technical school. The photograph was taken in the position of the eyes of a worker at one of the benches. Could one devise a more discomforting condition of glare under which to work?

Equally bad conditions have been found in sewing rooms and domestic science laboratories. A very faulty system used in a sewing room is shown in Fig. 12. Glaring lights greeted the worker from nearly every position in the room. The same criticism applies here as in Fig. 8. An especially striking instance was found in a "model" dining room where the young ladies were

being taught the principles of home-making. The furnishings were satisfactory and were arranged in a manner which would no doubt meet the approval of the seasoned house-wife, but above the dining table was a fixture containing four bare carbon lamps extending at an angle long ago condemned in lighting practise. Brackets too low on the side wall contained bare carbon lamps. The lighting system was wholly congruous but equally bad. This was one of the most discouraging conditions encountered for it showed that the director of the home-making course had no idea that good lighting is one of the most essential features in making a home attractive and comfortable. And further, these young ladies were graduated without a knowledge of the possibilities of lighting. The writer firmly believes that lighting has a sociological importance of an unrealized magnitude. These are just a few instances of bad lighting encountered in modern schools.

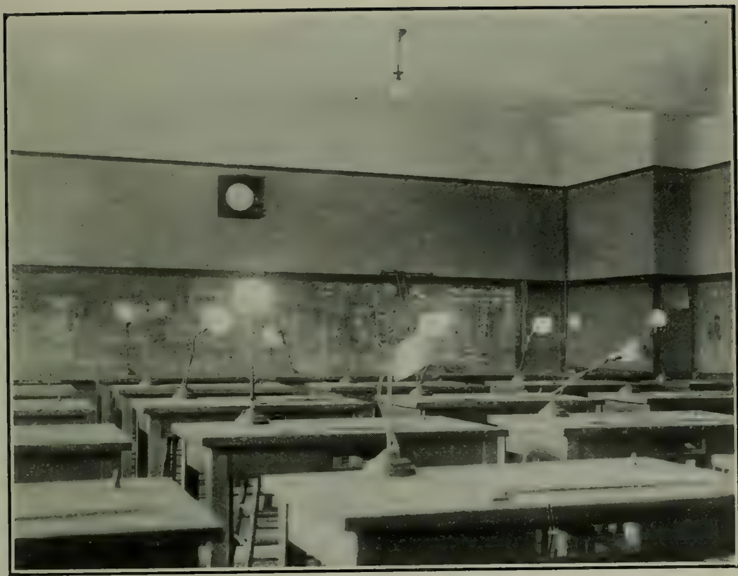
That rooms can be lighted well and inexpensively is shown in Fig. 13, illustrating a foundry lighted by the direct method using glass reflectors. The use of glass reflectors is commendable, for the ceiling is not left in complete darkness as is the case with the opaque reflector. Of course, this will be considered wasteful of light by some, but a foundry is a dingy place at best, so the waste is justified if it adds to the scanty cheerfulness.

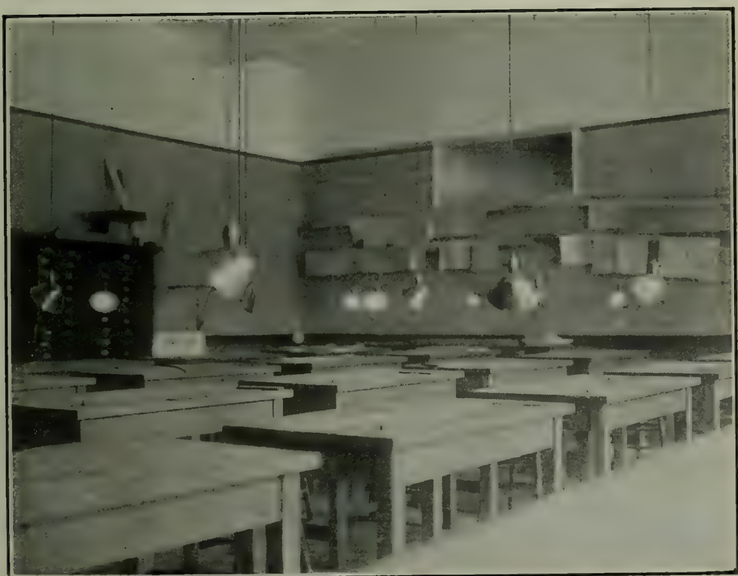
In Fig. 14 is shown a large class room lighted inexpensively by the direct method. This lighting is fairly satisfactory. It would be excellent if the clear incandescent lamps were replaced by bowl-frosted lamps. The latter should be used very generally in lighting systems similar to that illustrated in Fig. 14. The daylighting in this case is from two sides and the rear which is not satisfactory.

In Fig. 15 is illustrated an approved method of direct lighting. The lamps are hung high and screened by large, deep diffusing reflectors. The natural lighting is likewise satisfactory.

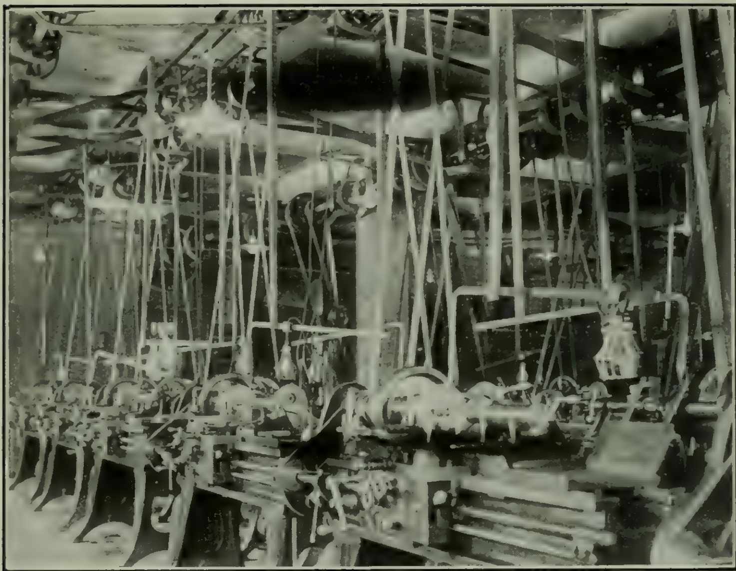
In Fig. 16 is shown a large assembly room lighted with direct units hung too low. This is a serious defect in this system. A high hanging-height would convert this very unsatisfactory condition into a fairly good example of so-called direct lighting. Note the glare from the glazed desks and doors.

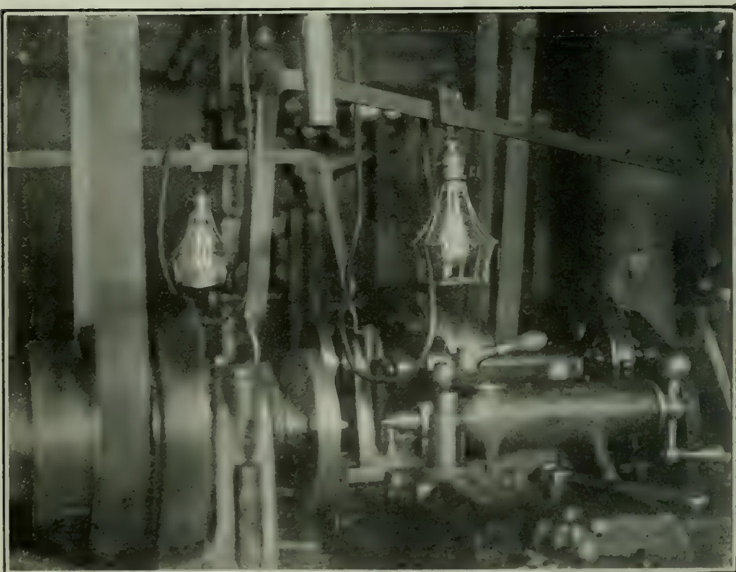
In Fig. 17 is shown a highly approved method of lighting for





Figs. 7 and 8.—Examples of faulty drafting room lighting.





Figs. 9 and 10.—Examples of faulty shop lighting.

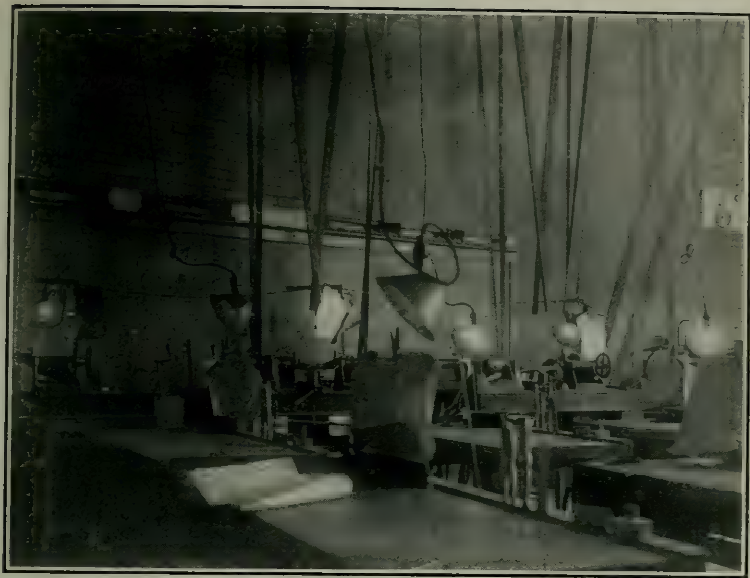


Fig. 11.—Faulty shop lighting.

Fig. 12.—Faulty lighting in a sewing room.

Fig. 13.—Satisfactory foundry lighting.

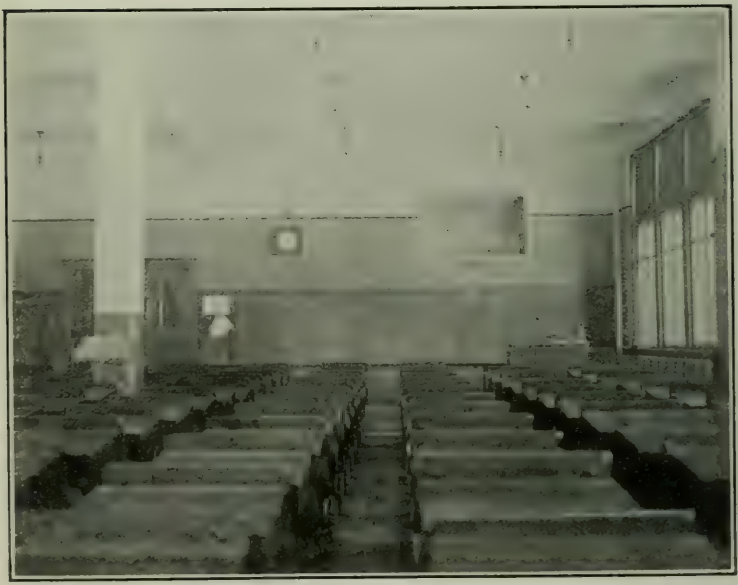


Fig. 14.—Satisfactory class room lighting.

Fig. 15.—An example of satisfactory direct lighting.

Fig. 16.—Unsatisfactory lighting in an assembly room. Units are hung too low.

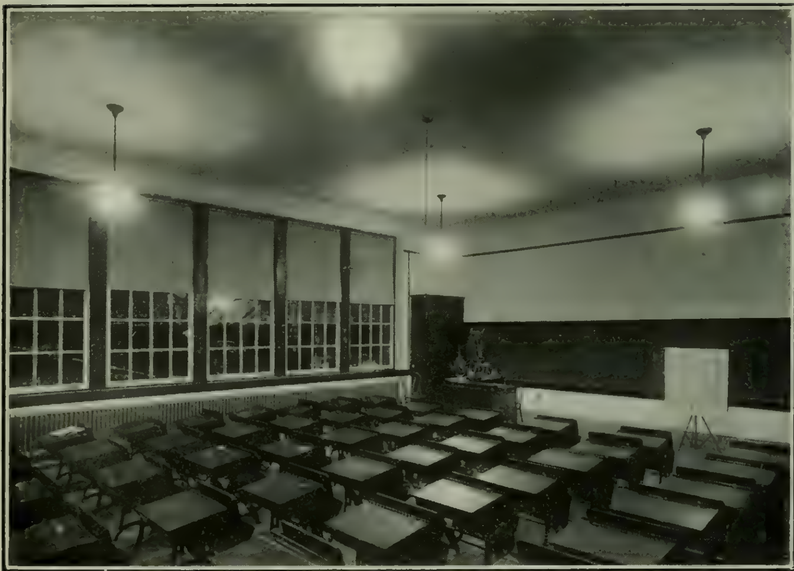


Fig. 17.—An example of excellent semi-indirect lighting.

Fig. 18.—An excellent example of indirect lighting.

class-rooms—the so-called semi-indirect system. The light is well diffused and the room has a cheerful appearance. The day-lighting is from the left and the window area ample. Note the glare from the desk top and image of the light source reflected from the window. This latter illustrates that in a broad sense proper lighting involves surroundings as well as the lighting units. In Fig. 18 is shown an excellent example of indirect lighting which is a very satisfactory system in the proper place. Many auditoriums and class rooms are well lighted by this method.

CO-OPERATION WITH SCHOOL AUTHORITIES.

The Illuminating Engineering Society through various committees and the individual efforts of members can be of considerable assistance to school authorities in improving lighting conditions, bringing about desirable legislation, and in promoting the instruction of pupils in the correct use of the eyes and of light sources.

The need for improvements in lighting has been shown from several viewpoints. Certain conditions commonly found produce glare from which discomfort arises and eye trouble may result. Bad lighting promotes near-sightedness which in turn handicaps the individual throughout life. Teach the pupil the fundamental principles of conserving vision and a life-long benefit has been bestowed upon him. But besides this, confront him with good examples of proper lighting and the combination will be so far-reaching in its effect that the benefit derived can not be estimated in terms of the cost. It might also be well to note here that in school lighting as in all other branches of illumination the efficiency of the system is the ratio of satisfactoriness to cost and not the reciprocal of cost. The Illuminating Engineering Society is prepared to co-operate with school authorities and it is to be hoped that the latter will recognize that their position is a keystone to the promotion of the conservation of our most important and educative sense-vision.

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DISCUSSION.

Mr. S. G. Hibben: Even though semi-indirect lighting is most excellent in schools, I do not consider direct lighting with open bottom reflectors to be taboo. Under quite a number of conditions, such as with units placed high enough to be well out of the line of vision, direct lighting reflectors are satisfactory—

in fact advisable whenever a good systematic maintenance or cleaning system would probably be lacking.

A larger number of direct than of semi-indirect units is necessary, both to secure a close approach to the same quality of broadly distributed or multidirectional light, and also in order to keep down the intrinsic brilliancies. The direct reflectors that are recommended for the schools are deep, to shield the filaments of the lamps, so that the proper sized shade for a 100-watt lamp in a classroom would be that which ordinarily would be used with a 150-watt lamp elsewhere.

The chief factors influencing the performance of the semi-indirect bowls are the density of the glass, and the hanging height. It goes without saying that ceiling colors are vital. I have found that of identically shaped bowls the medium density glass will produce 25 to 30 per cent. more illumination on desk tops than the heavy density opal. When a medium density bowl is lowered from the ceiling, the illumination beneath it increases; the reverse is often true when using a heavy density bowl.

I have considered it much better policy to use a larger sized light-density glass bowl, rather than a small sized heavy-density one. The common objection to the light-density glass is the relatively high intrinsic brilliancy. This may be overcome by using a larger bowl; and even though the first cost be greater than that of a smaller denser bowl, yet the increased efficiency or the larger amount of light on the working plane, will eventually more than over-balance the first cost.

Mr. G. W. Roosa: It might be a good plan to have rules on optical hygiene printed on small sheets and pasted in every school book. The necessity of safeguarding the eyesight and of better school lighting cannot be too strongly enphasized.

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ON THE CHOICE OF A GROUP OF OBSERVERS FOR HETEROCHROMATIC MEASUREMENTS.*

BY HERBERT E. IVES AND EDWIN F. KINGSBURY.

Synopsis: In making measurements on colored light with the flicker photometer the visual characteristics of the observers are of the utmost importance. A group of readers should be chosen whose average is that of an average eye. In this paper a method is described, by means of two test colors, for selecting a group whose average characteristics shall be those of the very large number who determined the photometric scale used by the authors.

In the photometry of colored lights the selection of observers is of exactly equal importance as the selection of an instrument and of conditions of illumination and photometric field size. Skill, previous experience and conscientiousness cannot make a man normally color sensitive if he is born otherwise. Consequently in selecting a group of observers who shall have in their mean a normal eye, one may pass over the best "reader" in a laboratory and use in his place the newest errand boy. In short, where colored light photometry is in question, one must in the choice of observers free one's mind as completely as possible from any previous criterion and establish a new one based on considerations of the nature of the observers' color vision.

In work recently presented before the Illuminating Engineering Society[1] we have carried out extensive measurements of differently colored lights, using throughout a definite photometric method. This method comprises in part the use of a

* A paper read at a meeting of the Philadelphia Section of the Illuminating Engineering Society, March 19, 1915.

[1] Experiments on Colored Absorbing Solutions for Use in Heterochromatic Photometry; Trans. I. E. S., No. 9, p. 795; 1914.

Additional Experiments on Colored Absorbing Solutions for Use in Heterochromatic Photometry; Trans. I. E. S., 1915.

certain design of flicker photometer, under stated conditions, and for the other part the use of a group of observers carefully selected so that their results shall be the same as for a normal or average eye. The instrument and method of use have already been described. It is the purpose of this paper to describe both the method of choosing the working group of observers and also a means by which other laboratories can select a group of similar characteristics.

The average eye now used in the laboratory of the United Gas Improvement Company is based on measurements made by sixty-one observers, this number being all that could conveniently be obtained during a period of several weeks, and being as well

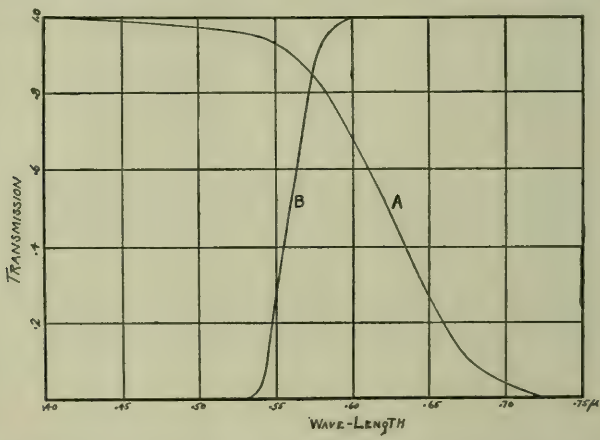

Fig. 1.—Spectral transmissions of two colored solutions used in the selection of a group of observers for heterochromatic measurements. A—53 grams copper sulphate to 1 liter of solution; B—72 grams potassium dichromate to 1 liter solution.

a large enough number so that the inclusion or exclusion of any observer in the group would affect the result by less than half of 1 per cent. The color measured was a monochromatic green against the light of a carbon lamp. This was not chosen as a criterion for general use, but was incidental to a determination of the mechanical equivalent of light and further details will be found in the account of that investigation.[2]

We shall first describe how our laboratory luminosity scale has been maintained on the basis of these measurements, after

[2] The Mechanical Equivalent of Light; *Physical Review*, 1915.
Measurements on a Monochromatic Green Solution; *Physical Review*, 1915.

which we shall describe means by which this same scale can be worked to in any laboratory.

The transmission of the special monochromatic green solution as given by the mean of sixty-one observers is 0.0437. Individual observers available in our laboratory vary from this as much as 12 per cent. on either side. In selecting a group for making a colored light measurement the procedure is simply to pick a group of at least five whose mean reading on the test color difference, as made and recorded once for all, is the true mean. Thus the group of seven used in one of the measurements on the blue solution previously described had obtained the following values on the monochromatic green:

	0.0474
	0.0432
	0.0416
	0.0453
	0.0398
	0.0471
	0.0418
Mean	0.0437

When any one observer of such a group was not available either another was selected of very nearly the same characteristics or, as was sometimes necessary, one or two other observers of the group were replaced by a different selection whose mean value from our record was again that of the sixty-one.

The luminosity scale maintained in this way has now been in use in our laboratory for a period of many months. It has proved eminently satisfactory. The different observers consistently retain their characteristic positions. Measurements made with different groups at various times have shown most excellent agreement.

In order to make this method of selection of observers generally available, and insure at the same time that the same luminosity scale is adhered to, we have thought it advisable to adopt a different test color difference than that incidentally obtained in the study of the mechanical equivalent of light. For this purpose we have worked out two colored solutions of inorganic salts which to the average eye, as determined by our measurements, should have equal transmissions of the light of a

standard carbon lamp. At the same time an effort was made to select transmissions each of which should give practically one end of the spectrum alone. The idea of this was that if a group of observers measures the ratio of the two halves of the spectrum correctly it will probably measure any of the ordinary much less pronounced color differences right.

The test colors which we now recommend are given by the following aqueous solutions:

Yellow solution: potassium dichromate—72 grams to 1 liter of solution.
Blue-green solution: copper sulphate—53 grams to 1 liter of solution.

These, placed in two carefully matched tanks of 1 centimeter thickness, *should transmit equal amounts* of the light of a standard "4-watt" carbon lamp, the measurement being made at 20 deg. C. by the flicker photometer under the conditions of illumination and field size previously described. In regard to the illumination, it is to be noted that the actual transmission of these solutions is close to 70 per cent. In order, therefore, to secure the equivalent of 25 meter-candles on a white surface the lamp and distance should be arranged to give 35 or more meter-candles, depending on the absorption of the optical parts of the photometer. Needless to say, as in all precision photometry, the test should be carried out by the substitution method, the two solutions being alternated on the test side.

The transmissions of these solutions have been established by a series of approximations involving a large number of measurements all made in accordance with our original method of maintaining the luminosity scale. This scale is now maintained by using the new test colors in exactly the same way as outlined for the monochromatic green and agrees, as it should, with the original scale. That is, a group selected by their measurements on these test colors as having a "mean eye" also possesses that characteristic when tested by their measurements on the monochromatic green solution.

A number of questions which arise in connection with the choice of a group of observers in this way can be answered from our experience. For instance, the question of what to do if enough observers are not available to make a balanced group is, we find, taken care of by giving double weight to one or two, in such way that the same weighting gives equality with the test

colors. Again the question arises as to the minimum number of observers necessary. Is one observer, for instance, enough, if he reads the test color difference correctly? We find in general that it is hardly safe to depend upon one observer who tests normal, because after all the test is to some extent arbitrary and is not an absolute guide to an observer's performance on all types of color differences. We have actually noted, however, that the mean result of a certain pair of rather extreme observers (whose values for $\frac{\text{yellow}}{\text{blue}}$ are respectively 1.12 and 0.90) in a long series of measurements is almost uniformly the mean of the group, suggesting that in many cases as few as two balanced observers would be sufficient, but we would nevertheless recommend at least five observers for precision work.

An important question which is frequently raised is that of the permanence of an observer's characteristics. Will the members of a group retain their relative positions over a period of time? A large number of observations, extending over nearly a year, have convinced us of the practical permanence of individual color vision characteristics, with very rare exceptions. We shall publish these data in another connection, but that portion obtained in this present study may profitably be presented here. In the series of measurements by which these two equal transmission solutions were developed, the preliminary work was done with a physical photometer (to be described shortly), after which two series of visual measurements were made, at an interval of about a month. In the first set seven observers participated and in the second eleven. Of these, six measured in both sets. In the following table we give the values of the ratios of transmission of the two solutions (the actual ratio of each approximation being taken as the unit) as obtained by these men at these two times:

	Ratio $\frac{Y}{B}$	
Observer	1st set.	2nd set.
1	0.957	0.946
2	0.973	0.965
3	1.002	1.052
4	0.910	0.904
5	1.042	1.043
6	1.068	1.074
Mean	0.992	0.997

It will be seen that with one exception the observers have repeated to 1 per cent. or better. This one observer (number 3) as it happens had, previous to this work, never read an optical instrument and was used in the work chiefly because of his availability at all times. The one exception need not, therefore, be given great weight. Even so, the mean value for this group of six, on these extreme test colors, is only ½ per cent. different in the two sets.

Another question is whether this method of selection could not be used for observers to work with the equality of brightness method. The answer is "yes," provided it were possible to make sufficiently definite and consistent settings by that method on the test color difference to yield unambiguous results. Actually the number of settings and the time which would be required definitely to determine an observer's characteristics by this photometric method would be prohibitive. The method of selecting observers is planned for the photometric procedure in which the flicker photometer is used, and it is recommended for that only.

This paper, together with those which have preceded, to which reference has been made, give full descriptions of instruments and methods by which uniform results may be obtained in different laboratories in the photometry of colored lights. A *luminosity scale* has been developed—a matter of as much importance in photometry as is a temperature scale in thermometry—to which these uniform results are referred. The test colors just described may be compared to the fixed points by which a thermometer is calibrated.

LIGHTHOUSE ILLUMINATION.*

BY RAYMOND HASKELL.

Synopsis: This paper describes the various forms of illuminants used in the lighthouse service and discusses their application by means of lenses and other means of intensification to lighthouses, buoys and light vessels.

In some form or other practically every system of illumination and every type of primary light source, has at some time been in use, or at least tried, for the purpose of lighthouse illumination. Even totally indirect lighting has been seriously advocated in the proposition to throw a strong beam upon the clouds. This, while it theoretically gives height to the signal and hence greater range of visability, would be impractical on account of the enormous energy required and the uncertainty of clouds.

History informs us that lighthouses existed long before the Christian Era, but, in comparison with modern installations they were built more as curiosities or monuments, than as aids to navigation. Later, however, a great many were constructed by the Romans, and the sites of these are indeed in many cases identical with those of modern lighthouses. The first lighthouse structure built in the United States was situated in Boston harbor. This, however, was partly destroyed during the Revolution, and the present Boston lighthouse, while on the same site, is a fairly modern structure.

The oldest existing lighthouse towers in the United States are situated on Sandy Hook and Cape Henlopen, but even in these cases the lanterns and superstructures are comparatively modern.

ILLUMINANTS.

In ancient days, and in fact up to fairly modern times, the illumination for lighthouse towers was produced by burning piles of fagots or other material giving a comparatively large flame. These were followed by the use of candles and various types of primative seed oil lamps. Oils have been, and still are,

* A paper read at a meeting of the Philadelphia Section of the Illuminating Engineering Society, November 20, 1914.

the principal sources of light used in lighthouses, the greatest advance in their use being in the improvement of the lamps and the manner of distribution of the light. Until recent times, vegetable or animal oils were the only ones used, the principal illuminant in the lighthouses of the United States being lard oil, but since the discovery of petroleum, kerosene, in one form or another, has formed the basis for light sources in the greater number of cases.

Both flat and round wicks are used, and for large installations burners with as high as eight concentric wicks have been developed. There are still a considerable number of five wick burners in use.

Since the advent of the mantle, wick lamps for the more powerful lights have been superseded in favor of the kerosene mantle type of lamp. This form of light source, at the present time, is the best, as to light efficiency and cost, known. Its only drawback is the fallibility of the mantle and hence the necessity for having a keeper to watch it occasionally and also to keep the lamps and accessories in proper shape.

In large installations it is necessary to have a keeper anyway, and therefore this system of illumination is almost universally used in these cases.

The first incandescent oil-vapor (kerosene with mantle) lamps used in this country were patterned after the French lamps, in which the kerosene is vaporized by the excess and waste heat of the mantle heating a tube containing the oil and situated over the mantle. This, however, had its drawbacks in efficiency and regulation, and another type has been developed which allows free passage of the light in all directions and gives a very high intrinsic brilliancy. This high intrinsic brilliancy, as will be readily understood, is the principal characteristic demanded by an illuminant for lighthouse purposes. The cost of this lamp for fuel is about 1 cent per 500 candlepower per hour, or including repairs and depreciation, about 1.5 cents per 500 candlepower per hour.

Electricity, on account of the high intrinsic brilliancy as exemplified in the arc and concentrated filament lamps, presents itself as the ideal source of lighthouse illumination. Its great drawback however is its cost and the difficulty of obtaining it at most light

stations. Simplicity and reliability are the watch words in the lighthouse service. Unless current can be obtained from power companies on shore, the use of electricity is prohibited by the cost of generating plants, the inability to make repairs on account of isolation of stations, and the necessity of employing skilled labor.

Where current can be obtained, as in some shore stations, the concentrated filament lamp is more or less ideal and is used satisfactorily. Even here it must be watched, as lamps will burn out and power lines will fail, but a lighthouse must stay lighted regardless.

The electric arc is theoretically ideal as a concentrated light source for use with lenses, but practically its drawbacks are many and various. It has been found expedient, therefore, to utilize this source only in a few instances, the most notable example being Navesink on the Highlands, just south of Sandy Hook. This is the most powerful signal in the United States, and correspondingly gives an exceedingly quick flash.

Gas, either in the form of enriched oil gas or acetylene, is a very important source of light in the lighthouse service, and is used particularly in buoys or small beacons, where great intensity is not demanded, and where it is impractical to have an attendant. These gas installations will operate without attention from three to six months, depending on the size of the burner and very little trouble is experienced with them.

LENSES.

While the intensity of the source is important, the greatest factor in lighthouse illumination is the means of intensifying or directing the light energy in order to obtain the most usable result.

This was first accomplished by the use of metallic reflectors. These are still used on some small light vessels, and when kept highly polished are not a bad installation. In these cases eight of these are so arranged on a carriage around the mast that they can be lowered to the deck and attended to without exposing the men to the weather.

The next development was the dioptric Fresnel, which was

followed by the complete lighthouse lens, containing both dioptric and catadioptric prisms. By catadioptric prisms is meant those above and below the central belt which direct the light in the desired direction, both by refraction and also by total reflection from the inner surface of the glass. This is shown by a lens profile. In the central belts the light energy is directed horizontally by refraction only. In the upper and lower prisms the light is first refracted, then totally reflected and finally refracted again. By means of these prisms the total energy from the source at the centre is theoretically emitted in a parallel direction. In cases of units which are known as fixed lenses, the prisms are evolved around a vertical axis, and the resultant beam is a series of parallel horizontal planes of light diverging in all directions, in azimuth. With flashing and range lenses the prisms are evolved around one or more horizontal axes, and the resultant beams are theoretically cylinders of light. Practically on account of the sizes of the sources the beams are solid cones of light whose divergence depends on the dimensions of the source, and whose intensity depends practically only on the intrinsic brilliancy of the source, and on the solid angles subtended by the lens panels at the focus. The flashing is produced by revolving the lens around the source.

The mariner prefers a fixed light as it gives him something steady to run by, but such lights are naturally lacking in intensity and are often confused with shore lights. The flashing light is very powerful but is of short light duration. With lenses of the same focal length, the ratio of the period of luminosity to period of darkness is indirectly proportional to the intensity of flash. Where high power is not needed, but where it is desired to produce a distinctive light, it is customary to use a fixed lens, but to cut off the light at definite periods by means of blanking sections of the lens, and revolving it about the source of light. This can be accomplished by extinguishing or blanking shutters which periodically cover up or cut off the light from the source.

In order to utilize the light energy which is lost when a lens panel is blanked off, it has been found expedient to install silvered spherical mirrors in place of these blanking panels. By properly arranging the mirrors the light, which would strike a blank

panel, can be reflected back through the source and out through the lens on the opposite side, thereby intensifying that beam very greatly. With sources of illumination that are transparent, as acetylene gas, this method is very efficacious, but with sources which are quite opaque, as mantle lights, the gain from this scheme is scarcely 25 per cent. To obviate this loss the idea was conceived that instead of sending the energy back through the focus, it could be sent back alongside of the focus just missing the mantle. Theoretically this would not produce good results, as the lenses are designed for a point source at the focus, but practically the sources are generally so large that the fact that the image is not at the focus is scarcely realized, and from 80 to 85 per cent. of the otherwise lost energy can be utilized in useful light. With fixed lenses this intensifies the beam. When used with flashing lenses it increases the relative light period.

In using this principle of offset mirrors it has been found most practical to split the mirrors vertically, and so set them as to send the reflected light on both sides of the mantle instead of all on one side.

As mentioned above the usual method of producing occulting or flashing lights when gas or electricity is not used for the illuminant is by means of revolving the lens. This is done by clockwork actuated by weights. The lenses are often very heavy and are generally supported on chariots, ball bearings or floated in mercury. For the heavy lenses the mercury float method is found to be the best. By the proper design of mercury float, a two-ton lens can be carried on less than 50 pounds of mercury and the whole thing can be revolved by a few ounces constant force. This requires, however, that the parts of mercury float outfit shall be machined and set up exceedingly true, and also that the lens shall be very well balanced. In order to use oil-vapor lights, it is necessary on account of the tanks containing oil and air under pressure, that the lamp shall be stationary and the lens revolve around it.

The most powerful flashing lens ordinarily used is what is called the bivalve. This consists of two hemispherical shaped panels, the prisms of which are so arranged as to concentrate practically all the light emitted by the source into two diametri-

cally opposite beams. The flash emitted by these bivalve lenses is very powerful, but is of short duration, in many cases of less than one tenth second duration. When it is desired to utilize the beam in only one direction, as in the case of a range lens showing light only in one direction along a channel, one half of a bivalve can be used and intensified by the substitution of mirrors for the other half. This condenses and directs all the light emitted by the source in one direction in a search light beam.

By proper design of prisms and panels it is possible to flash numbers, as in the case of Minots Ledge, which flashes 1-4-3, or as in other cases to make combinations of red and white flashes. These special combinations are used in cases where a number of lights together are likely to produce confusion.

The manufacture of lenses is quite a delicate operation, and until lately such work has been done abroad. This has been due partly to the fact that the largest factor in the cost is labor, which can be obtained much cheaper abroad than here, and also to the fact that the demand has not been sufficient to warrant the initial outlay necessary.

Recently, however, American manufacturers have gone into this industry and by the use of machinery are making better lenses than those obtained abroad, and it is believed it soon will be a paying proposition to them. The advantage of the American made lens over the foreign one lies in the use of machinery instead of hand labor, whereby all similar prisms are exactly alike and interchangeable, and repairs can be easily made. In foreign lenses the prisms rarely are the same and repairs are very expensive.

LIGHT INTENSITY.

A great many attempts have been made to compute the candlepower values produced by various lenses, but there are so many factors entering into this computation that a formula becomes too loaded down to be workable. They all end up by making some assumption or other which is never practical and vitiates the whole computation. In working out candlepower values the United States Lighthouse Bureau has used the empirical method, obtaining all the data it could and then using simple formula for interpolation. The values were obtained by actually measuring

such lenses as were available with the different sources of lights used in the service.

The following results are worth noting. With small lenses the candlepower increases up to 150 feet and then remains constant no matter how far away it is taken. With large lenses the maximum is reached at 250 to 300 ft. (75 to 90 m.), and further increase of distance causes no change. This is largely due to the fact that the sources of light are fairly large. As a general rule the maximum is reached soon after a point is reached where all the prisms fill with light.

Fixed lenses with the same light source are found to vary in candlepower directly with the diameter; flashing lenses of similar construction vary approximately as the square of the diameter decreasing and departing, however, from this law somewhat as the larger lenses are considered. This is probably due to the fact that the prisms in the larger lenses are thicker and not so well set as the medium sized ones. With fixed lenses the candlepower varies directly as the intrinsic brilliancy and as the width of the light source, but does not depend on its height. With flashing lenses the candlepower depends only on the intrinsic brilliancy, the large sources producing only more divergence of beam and no increase of candlepower.

The dioptric portion of the lens, approximately 30° above and below the central plane, produces about 60 per cent. of the light, the upper catadioptric portion 30 per cent. and the lower 10 per cent.

All of the above facts would be naturally foretold by geometrical optics, but it is always pleasing to have theory so well corroborated.

The brightest light in the United States is on the Highlands of the Navesink where an electric arc is intensified by a second order bivalve lens. It is estimated at 25,000,000 candlepower.

BUOYS.

The lighted buoy is more or less a modern invention. At one time an attempt was made to have a string of buoys in one of the channels of New York harbor lighted by electricity and supplied by a cable from the shore. They gave so much trouble,

however, that they were abandoned. The next development was the use of oil or Pintsch gas, each buoy being a unit by itself. The gas is contained in the body of the buoy under up to 180 pounds (12 atmospheres) pressure and burns in a protected lantern at the top. In order to save gas and give character to the light, a mechanism is installed in the lantern which automatically and periodically turns the gas on and off. A small flame or pilot burns continuously in order to light the gas when it is automatically turned on. The mechanism is simple and operated by the gas pressure, and barring accidents will operate as long as there is gas in the buoy. Ordinarily these buoys will run without attention from four to nine months, depending on the flashing period of the light.

These buoys are very easily filled at their stations by simply lashing the buoys to the side of a lighthouse tender, attaching a hose and pumping the gas into them from a large storage holder carried on deck. The crews of these vessels become quite expert in securing these buoys for attention even in rough seas, and it is surprising how little damage is done to them.

The candlepower of an ordinary oil gas lantern, however, is low and in hazy weather especially it cannot be seen at any great distance. To increase its light intensity, in many cases the gas is burned with a mantle. The use of the mantle introduces, however, a more or less uncertain factor. Sometimes a mantle will operate for many months satisfactorily without failure, while another mantle from the same manufactured lot will fail very quickly. These lights therefore are generally used in places where they can be observed every few days and given attention if necessary.

The most modern gas illuminant is acetylene. This is burned in a lantern more or less in the same manner as oil gas, only the mantle is not used. This gas, however, cannot be compressed with safety into the body of the buoy, and so is stored in tanks, dissolved in acetone. These tanks fit into pockets in the buoy and are so arranged that they can be easily removed and replaced on station by a boat alongside.

Another form of buoy more or less in use generates the acetylene at low pressure directly from calcium carbide stored in the

buoy. Theoretically this should be the most economical method to produce acetylene, but practically it is unsatisfactory. Owing to high seas and waves the buoys often do not generate evenly and considerable gas is lost. It is impossible to tell exactly how long a buoy is going to run which makes it administration costly on account of tender costs. There is a buoy of this type in New York harbor which ran sixteen months on a single charge, and then the next time it went out in two months.

In order to save gas in the day time it is possible to equip gas apparatus with a mechanism which is operated by the light of the sun and turns the gas off in the day time. These so called "sun valves" operate quite satisfactorily, especially on large installations where considerable gas is consumed, but with small lanterns the depreciation and repairs of the sun valve is greater than the cost of gas saved. This is especially true of buoys where the danger of being damaged by passing vessels is great.

LIGHT VESSELS.

Perhaps the most important aid to navigation is the light vessel. These are vessels anchored at well known sailing points whereby the mariner can get a perfect idea of his position in thick weather without the danger usually attendant in running too near a lighthouse. Light vessels being anchored in reasonably deep water, the mariner runs close to them and can get an accurate point of departure for shaping his course, while lighthouses being on land the mariner cannot run near to them and especially in thick weather must more or less guess at his position. In addition to signal lights these vessels all carry an air fog signal and most of them submarine bells.

The characteristic lights of a light vessel are carried at or near the mast head and consist practically of the same systems as enumerated above. The small vessels are equipped with oil lamps with reflectors or with small lenses and lanterns. These are arranged on frame work around the mast so designed that it can be lowered to the deck and given proper attention without the necessity of the men going aloft in bad weather.

A large number of vessels are being equipped with gas apparatus, particularly acetylene on account of its simplicity and

ease of handling. This gas apparatus has the further advantage that the lanterns can be fixed permanently at the mast head and thus gain several feet in height over the oil light installations.

Most of the larger vessels are equipped with electric plants and the sources of illumination are concentrated filament 250-watt tungsten lamps in 300 mm. lanterns. These give a most satisfactory light and require little attention, the only drawback being the necessity for a complete electric plant. One vessel, "Ambrose" at the entrance to New York harbor is equipped with flaming arcs in 300 mm. lanterns. These of course give a very powerful illumination, but it is really greater than is necessary to correspond with the elevation of the lanterns. These lights are so bright that there is complaint that they prevent the pilots from detecting other ships approaching from back of the light vessel.

Both light vessels and lighthouses will soon be displaced in a large number of cases with big buoys. These are being made now with very heavy bells and strong whistles, and on account of the lower initial cost and maintenance, several can be used instead of one light vessel, for the same cost and a much broader system of guide posts of the sea can be established. The mariner will simply run between buoys, a few miles apart.

SOME DATA ON ARTIFICIAL DAYLIGHT UNITS.*

BY CLAYTON H. SHARP.

By projecting a spectrum on to a card covered with skeins of worsted of all the principal spectral colors, including also purple, it was shown how the colors of fabrics vary as seen in different colored lights. Thus a red worsted is black in green and blue light and a blue one is black in the red light. Therefore it is necessary in order that colored fabrics may always be seen alike that they always be viewed under light of the same spectral composition, having that is, the same relative intensities of each of the colors. As a standard of composition of this sort, daylight is chosen and this is called "white light."

The colors of fabrics are obtained in one of two ways; either by the use of a pure dye or by mixing two different dyes together. For instance, a green may result from the use of a pure green pigment or it may result from the admixture of blue and yellow. Two greens differently made up might match in one light, whereas with light of a different spectral composition, they would be differently affected and hence would not match. The use of the daylight equipments is to provide this standard white light of a given spectral composition for the purpose of matching colors. In certain respects an equipment of this kind is better than daylight, inasmuch as it is always of a fixed value and does not vary continually as daylight does, both in color and intensity.

The following daylight equipments were exhibited and data obtained at the Electrical Testing Laboratories and made available through the courtesy of the Lamp Committee of the Association of Edison Illuminating Companies were given.

The principle of the operation of these equipments is that by the interposition of a bluish screen between the light source and the object to be viewed, the excess of red and yellow in the light source is removed, and the spectral composition of the resultant light becomes the same as that of daylight.

* Summary of a lecture delivered before a meeting of the New York Section of the Illuminating Engineering Society, November 14, 1914.

Description of equipment	Character of the light source	Character of the screen
A	Moore carbon dioxid tube	None.
B	Special Welsbach mantle	Greenish-blue pebbled glass and purple gelatin.
C	Intensified arc	Composite of small pieces of blue, green and clear glass with diffusing glass.
D	Gas-filled tungsten lamp	Bluish glass.
E	Gas-filled tungsten lamp	Globe of bluish glass, sand-blasted on the interior.
F	Gas-filled tungsten lamp	Globe of blue glass flashed with opal.

DATA ON ILLUMINATION PRODUCED.

Equipment B.

The illumination values found are shown on the accompanying chart. The center of the field was much brighter than the edges.

Equipment C.

The following values were obtained:

Location of test station	Horizontal foot-candles 18 in. below screen	3 ft. below screen
Directly beneath center of screen........	50.0	13.4
1 ft. out from center of screen..........	26.0	13.2
2 ft. out from center of screen..........	5.6	8.4
3 ft. out from center of screen..........	1.4	2.5
4 ft. out from center of screen..........	—	1.0

Equipment D.

The following values were obtained:

Location of test station	Horizontal foot-candles 1 ft. below screen	18 in. below screen
Directly beneath center of screen..........	52	18.0
3 in. out from center of screen..........	36	—
6 in. out from center of screen..........	11	8.5
1 ft. out from center of screen..........	4	3.0
18 in. out from center of screen..........	—	1.5

Note: Illumination very non-uniform. Bright spot directly beneath unit.

A (on left)—Moore carbon dioxid tube; B (on right)—A special gas mantle daylight producer.

C—Intensified carbon arc lamp with color screen.

F—Tungsten lamp in a blue glass globe flashed with opal.

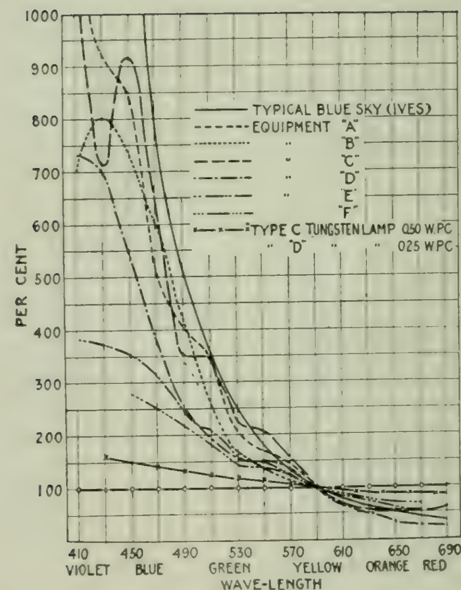

Fig. 1.—Spectrophotometric curves of the daylight equipments.

ABSORPTION DATA.

Equipment C.		
Arc lamp unequipped, mean spherical cp.	151	
Arc lamp with reflector, mean spherical cp.	107	
Arc lamp with reflector and color screen	11	
Absorption due to screen	90	per cent.
Equipment D.		
Lamp equipped with reflector, mean spherical cp.	57.8	
Lamp equipped with reflector and color screen	3.56	
Absorption due to screen	94	per cent.
Equipment E.		
Absorption	64	per cent.
Equipment F.		
Absorption	73.5	per cent.

The spectrophotometric curves of these equipments are given in the accompanying figure. Daylight curve ascribed to Ives refers to the blue sky.

The Moore carbon dioxid tube has been suggested as a standard of white light and may in this case be used as a proper standard for comparison.

BOOKS ON ILLUMINATION.

The table* on the following pages gives a classified analysis of all the available books, in English, pertaining to illuminating engineering. It indicates the possible utility of these books for illuminating engineering practise. The distributions under the various subject-headings constitute, of course, an index rather than a precise analysis of the contents of the books. Moreover, the classification, as might be expected, is necessarily more or less arbitrary. For example, "Private House Electric Lighting" by Taylor describes small plants for generation of electricity, and the practical wiring and placing of lamps in residences. It has been classed under the heading "G," but there are also good reasons for classing it under "D," "M," "Q," or "U."

Catalog of Various Subjects Covered by Table I.

A. Physical basis of light production.
B. Physical characteristics of sources.
C. Chemistry of light production.
D. Electric illuminants.
E. Gas and oil illuminants.
F. Incandescent gas mantle lamps.
G. Electric and gas lighting (gen. mfgr. and dist.)
H. Units, standards and terminology.
I. Photometry.
J. Architecture.
K. Physiology and psychology.
L. Calculations.
M. Interior illumination.
N. Exterior illumination.
O. Reflectors, glassware, etc.
P. Fixtures.
Q. Commercial aspects of electric and gas lighting.
R. The Illuminating Engineering Society.
S. Illuminating engineering.
T. Color.
U. Miscellaneous.

* This table, which was prepared by Mr. Norman Macdonald, has been abstracted from the annual report of the 1913-1914 Committee on Education of the Illuminating Engineering Society.

TABLE I.—BIBLIOGRAPHY AND SUMMARY SHOWING APPROXIMATE NUMBER OF PAGES GIVEN TO VARIOUS TOPICS.

Illuminants

Title	Author	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Arc Lamps and Accessory Apparatus	J. H. Johnson (1911)				110				11													
Electric Arcs	C. D. Child (1913)				180					10												
The Electric Arc	H. Ayrton (1898)				443					14												
Electric Arc Lamps: their Principles, Construction and Working	Zeidler & Lustgarten (1908)				179				5													
Electric Lamps	M. Solomon (1912)	9	9		216				4	68												
Electric Lamps and Electric Lighting	J. A. Fleming (1894)		25		83			50						10								
High Efficiency Electric Illuminants and Illumination	R. W. Hutchinson, Jr. (1911)				170					7				60	24							7
Incandescent Electric Lamps and Their Application	D. H. Ogley (1914)	8			49				10	18		5	7									

Lighting Practise.

Title	Author	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
The American Practice of Gas Piping and Gas Lighting in Buildings	Wm. P. Gerhard (1908)							249										9				
The Art of Illumination	L. Bell (1912)				68	23	17		25			24		72	55	37					12	
Electrical Illuminating Engineering	G.S. Barrows (2nd ed.-1908)				90				22	41			38			16				12		
Electricity for Everybody	R. B. Matthews (1912)																	300				
Electric Incandescent Lighting	Houston and Kennelly (2nd ed.-1902)				221			206		23										12		

Lighting Practise.—(Continued).

Title	Author	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Electric Lighting	F. B. Crocker (4th ed.-1901)				110			826										23				
Electric Lighting and Its Practical Application	J.N. Schoolbred (1879)				30			27														
Electric Lighting and Miscellaneous Applications of Electricity	W. S. Franklin (1912)				25			155		40				14	14	5						
Elementary Principles of Illumination and Artificial Lighting	A. Blok (1914)	12	12						19				43	35	31	13				23		
Elements of Electric Lighting	P. Atkinson (10th ed.-1901)	221			53																	
Factory Lighting	C. E. Clewell (1913)													156								
Gas Analysts' Manual	J. Abady (1902)								31	96												396
Gas Centenary Lectures	American Gas Institute (1912)					50		100														25
General Lectures on Electrical Engineering	C. P. Steinmetz (1910)	30			20																	
Lighting by Acetylene	F. Dye (1902)							182														
The Lighting Book	F. L. Godinez (1913)											31		69		10						
Modern Illumination: Theory and Practice	Horstman and Tousley (1912)				40					24		14		40	5	15	3			83		30
Obstruction to Light	H. B. Molesworth (1902)																					300
The Orientation of Buildings or Planning for Sunlight	Wm. Atkinson (1st ed.-1912)																					139
Practical Illumination	Cravath and Lansingh (1907)	4	4		39	16						4	12	204		55						
Private House Electric Lighting	F. H. Taylor (1911)							144														
Science of Illumination	Dr. L. Bloch (1914)		24						10	24			82							7		
Tables for Computation of Illumination	W. B. King (1908)												20									

Photometric Measurements.

Title	Author	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Electrical Photometry and Illumination	H. Bohle (1912)	20			35				14	47			30			12				43		
Illumination and Photometry	Wm. E. Wickenden (1st ed.-1910)	11			43	14			12	37		9	12		6	9				19		
Illumination: Its Distribution and Measurement	A. P. Trotter (1911)								26	226										37		
Photometrical Measurements	W. M. Stine (1909)	27			10				108	103		12										
A Treatise on Industrial Photometry with Special Application to Electric Lighting	A. Palaz (1896)									310												

Physics of Light.

Title	Author	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Introduction to Study of Color Phenomena	J. W. Lovibond (1905)																				46	
Light	R.C. Maclaurin (1909)	223																			23	
Light: A Course in Experimental Optics	L. Wright (1892)	400																				
Light: Its Influence on Life and Health	F. Winslow (1867)											300										
Light: Visible and Invisible	S. P. Thompson (1897)		245									45										
The Nature of Light: With a General Account of Physical Optics	Dr. E. Lommel (1892)	352																				
Outlines of Applied Optics	P. G. Nutting (1912)	200	10							14		4										
Optic Projection	Gage and Gage (1914)																					703
Physical Optics	R. W. Wood (1911)	600																				
Spectrum Analysis	J. Landaueer (1st ed.-1898)		10																			
Studies in Light Production	R. A. Houston (1912)		20		33	15			13	14												11
The Theory of Light: A Treatise of Physical Optics	R. C. Maclaurin (1908)	160											160									

Principles and Theory of Illumination.

Title	Author	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Color Value	C.R. Clifford (1907)																				90	
Color Vision	Capt. W. deW. Abney (1894)											220									8	
The Electric Light: Its History, Production and Application	Alglave and Boulard (1884)				177	10		176										50				
Lectures on Illuminating Engineering	Johns Hopkins Lectures (1910)	24	72	16	48	60	20	150	24	96	18	80		90	90	46	14	95				7
Light and Electricity	J. Tyndall (1874)	194																				
Light, Radiation and Illumination	P. Högner (1906)	56																				
Radiation, Light and Illumination	C. P. Steinmetz (1909)	77	24	3	33	20				20		44	14			24				50	5	
Students' Text-Book of Color	O. M. Rood (1908)											30									325	
Specialties.																						
Color Matching on Textiles	D. Patterson (1901)											10									130	
The Colorado Springs Lighting Controversy	H. Floy (1st ed.-1908)																	317				
Electric Light for the Farm	N. H. Schneider (1911)							85														
Electric Lighting for Marine Engineers	S. F. Walker (1892)																	293				
Electric Ship Lighting	J. W. Urquhart (1892)																	269				
Searchlights: Their Theory, Construction and Application	F. Nerz (1907)				135																	
	Totals	2628	455	19	2640	208	37	2350	334	1232	18	832	418	750	225	242	17	1356	0	286	639	1618
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A PRACTICAL STUDY OF CAR LIGHTING PROBLEMS.*

BY W. G. GOVE AND L. C. PORTER.

Synopsis: This paper describes very exhaustive tests conducted by the New York Municipal Railway Corporation in order to determine the best method of lighting the 600 new cars under construction for the new subway in New York City. Direct, semi-indirect and totally indirect lighting systems were tried in a full sized template car, built for the purpose. Both standard equipment and equipment especially constructed for the purposes were tested, the construction of the car being changed where necessary. As a result of the tests, the system finally adopted consisted of a single row of 56-watt tungsten railway lamps located down the center line of the ceiling and equipped with intensive type opal glass reflectors, this system offering the best combination of desirable factors, including good lighting, reasonable installation cost and low maintenance cost.

When the plans for the new subway in New York City were being completed, it was decided that the six hundred cars should be the latest word in car construction in every detail. Many new and interesting mechanical and electrical devices, which have been described in the various technical bulletins,[1] were decided upon for these cars. Not the least of these most up-to-date factors was the lighting of the cars. The size, interior seat arrangement, finish and construction of the cars presented many new problems to be solved in choosing a lighting system which would meet satisfactorily the following desiderata:

(1) Quantity of light; it being desirable to have an average intensity of not less than 3 foot-candles on a horizontal plane 42 in. (1.06 m.) above the floor, at 85 per cent. normal voltage.

(2) General effect and appearance of lighting system with lamps lighted or extinguished.

* A paper read at a meeting of the New York Section of the Illuminating Engineering Society, March 11, 1915.

[1] *Electric Traction*, A. E. R. A., Dec., 1914.

(3) Lack of eyestrain for both seated and standing passengers, involving not only intensity and direction of light, but also glare and possible shadows cast by standing passengers on the reading matter of seated passengers.
(4) Efficiency.
(5) Installation and maintenance expense.
(6) Depreciation of equipment in service.

In order to make a thorough study of these problems a series of tests were conducted in a full-sized model car constructed for the purpose. This car was 67 ft. 3 in. (20.42 m.) overall, by 9 ft. 10 in. (3 m.) wide, by 12 ft. 3 in. (3.73 m.) high. The in-

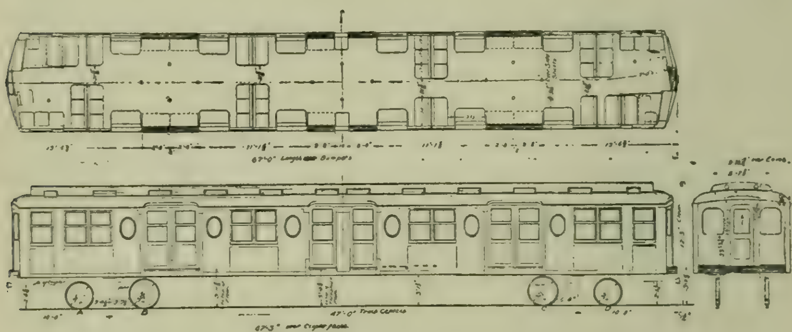

Fig. 1.—Plan and elevation of New York Municipal Railway Corporation's subway tempate car.

terior dimensions of the body used in the tests were 65 ft. (19.81 m.) long by 9 ft. (2.74 m.) wide. Fig. 5 is an exterior view of the car. The interior car finish was white enameled headlining and walls, down to the window sills. Below the sills the walls were painted grey. The floor was concrete and the seats upholstered in yellow rattan. Fig. 1 shows the interior seating arrangement and gives the general dimensions of the car.

Photometer tests were taken to supplement such data as observation of the general appearance, installation and maintenance cost figures, etc. The photometric measurements were not made with the intention of comparing the efficiency of any particular types of illuminating devices or accessories thereto; though the

average intensities obtained were used in securing the relative utilization efficiencies of the various lighting systems tested.

In making the photometer tests stations were chosen 2 ft. apart in a horizontal plane 42 in. (1.06 m.) above the car floor, over one quarter of the floor area. The entire car, however, was equipped with lighting units. Five readings were taken at each station, on a portable photometer, recalibrated before each test. In order to make one reading comparable with any other, simultaneous voltage readings were taken, as it was found to be impracticable to hold constant voltage on the lamps. Each photometer reading was corrected to normal voltage from the characteristic curves of the lamp and the five corrected readings averaged to obtain the station value. In obtaining the average intensity for the entire car, weight was given the stations in proportion to the area covered. The illumination values were also calculated for 85 per cent. normal voltage, in order to see what illumination would maintain under that condition.

The same lamps, as far as practicable, were used in the various reflector equipments. As the tests were made to find out approximately what would be the average operating condition in new cars, and not to determine the exact efficiencies of the different reflectors, figures were based on the manufacturers' data book ratings of the lamps.

It was decided before the tests started that tungsten filament lamps would be used for illuminants, the question being as to the best method of applying the lamps. Three systems of illumination were tried out, *i. e.*, (a) direct lighting, (b) semi-indirect lighting, (c) totally indirect lighting. In working up various applications of these three systems, a study was made of existing installations, supplemented by many suggestions for improvement from various lighting experts and practical railway men. In order to carry on the tests the interior construction of the car was altered when necessary.

Photographs of the interior of the car were taken with the lamps burning. The exposures were timed to exactly two minutes. These photographs were intended for comparative purposes only. They have no bearing on the photometric readings,

except to indicate (in a comparative way) the high and low lighting throughout the car.

The direct lighting tests made were as follows:

DIRECT LIGHTING TESTS.

No. 1.—The lighting units used in this test consisted of a single row of 14 6-in. opal glass reflectors (see Fig. 6) mounted along the center line of the ceiling and spaced as shown in Fig. 2. Ten of these reflectors were equipped with 56-watt clear bulb tungsten railway lamps (wired in two circuits of five lamps each in series) and the remaining four with 10-watt clear bulb tungsten emergency lamps.

The variation from even spacing shown on Fig. 2 was necessary on account of the construction of the model car, but would be corrected in the cars as finally built. The light distribution (Fig. 2) was good, though it had points of high intensity under the emergency lamps, due to the small lamp in large reflector. No bare lamp filaments were visible along the normal line of vision. The efficiency of the system was high, installation costs—on account of the single row of large units—were low, and maintenance was good, the smooth surface of the reflectors facilitating rapid cleaning. The general appearance of the lighting system in the car was pleasing (see Fig. 7) and the illumination good. averaging 5.7 foot-candles at normal and 3.2 at 85 per cent. voltage, with an energy consumption of 1.03 watts per square foot. There were 5.54 effective lumens per watt and the effective utilization efficiency was 68.7 per cent. It is interesting to note that the utilization efficiency in an ordinary dark yellow trolley with similar equipment is about 30 per cent., showing the great advantage (from an efficiency-of-light-utilization standpoint) of the white enamel interior finish.

No. 2.—The second direct lighting test was similar to the first, except that clear prismatic reflectors were used. The change of reflectors raised the average foot-candle intensity to 6.1 at normal and 3.4 at 85 per cent. voltage. The effective lumens per watt were increased to 5.90 and the utilization efficiency to 73.2 per cent. The maintenance of this equipment would be slightly

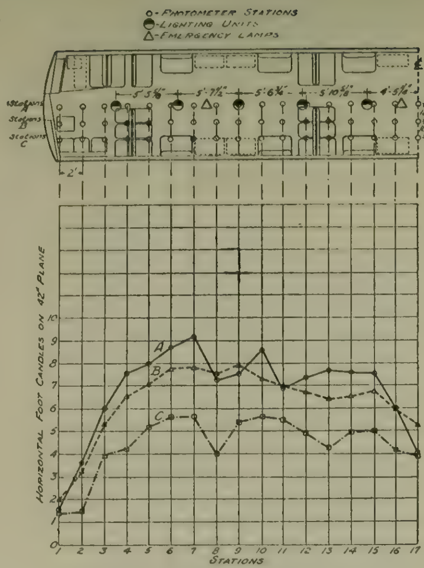

Fig. 2.—Light distribution from ten 56-watt, 120-volt, railway tungsten filament lamps in white glass reflectors, and four 10-watt, 115-volt tungsten emergency lamps with same reflector. Installation shown in Fig. 6.

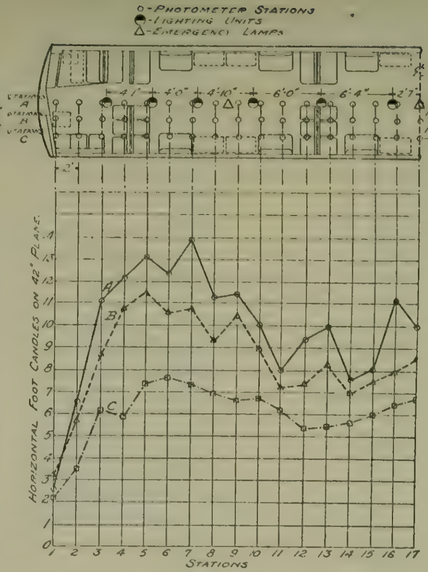

Fig. 3.—Light distribution from twelve 80-watt, special opal-dipped bulb, turnip-shaped, tungsten lamps. Installation is shown in Fig. 8.

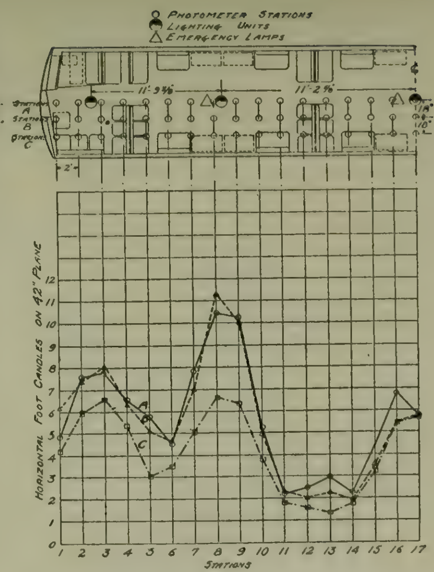

Fig. 4.—Light distribution from five 94-watt, 120-volt tungsten railway lamps in prismatic reflectors and four 10-watt, 120-volt emergency lamps in prismatic reflectors. Installation not shown.

higher than with the glass used in the aforementioned test, due to cleaning the prismatic glass. There was also a little more glare, though not an objectionable amount. The choice between these two reflectors, therefore, is largely one of esthetic taste.

No. 3.—In the third direct lighting test 5 94-watt clear tungsten filament railway lamps, equipped with clear prismatic reflectors were located in a single row down the center line of the ceiling. Four 10-watt tungsten emergency lamps in clear prismatic reflectors were located between these. The resultant average intensity in the car body was good, but due to the relatively low hanging height and wide spacing of the units the distribution was very uneven (see Fig. 4). The installation and maintenance of the system would be low, on account of the small number of large units to install and clean. The average foot-candles obtained were 5.0 at normal and 2.8 at 85 per cent. voltage. The energy consumption was 0.87 watt per square foot; effective lumens per watt 5.75; and effective utilization efficiency 71.5 per cent.

No direct lighting tests were made with lighting units located on the half decks. Previous experience and tests had shown that center-deck direct lighting may produce perfectly satisfactory illumination, free from sharp shadows and glare. It was felt that the possible gain of a few per cent. in efficiency with the half-deck lighting did not warrant the additional installation and maintenance expense (due to a larger number of smaller units to install and clean) accompanying this system of lighting.

SEMI-INDIRECT LIGHTING TESTS.

No. 1.—A very interesting method of lighting was used in the first test. Twelve special 80-watt 95-volt turnip-shaped tungsten lamps, opal dipped over the tip half, were installed down the center line of the ceiling. Each lamp was suspended by an inverted white enameled cone, shown in Fig. 8. Three 10-watt tungsten emergency lamps were also used in small rosettes. The 80-watt lamps were connected six in series. All of the filament of the 80-watt lamps was located below the center of the bulb; hence, none of it was in the line of vision. The opal on the lower half of the bulb served a double purpose, *i. e.*, to protect

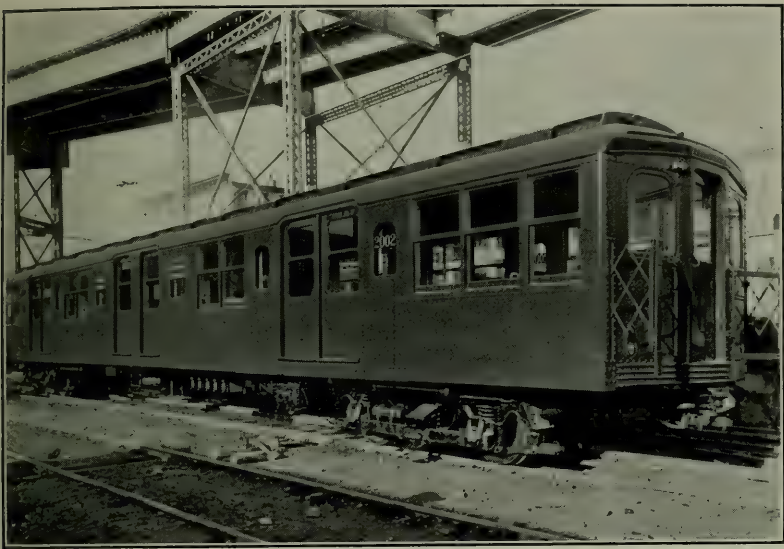

Fig. 5.—Outside view of New York Municipal Corporation's subway car.

Fig. 6.—Showing installation of 56-watt railway tungsten filament lamps in white glass reflectors.

Fig. 7.—Lighting effect of installation shown in Fig. 6.

Fig. 8.—Installation of 12 special 80-watt, 95-volt, turnip-shaped, opal-dipped bulb, tungsten filament lamps, suspended without reflectors from white enameled cone shaped fixtures.

Fig. 9.—Installation of 56-watt tungsten filament railway lamps in special convex reflector.

Fig. 10.—Semi-indirect lighting; each bowl contains two 94-watt tungsten filament railway lamps and one 10-watt tungsten emergency lamp.

Fig. 11.—Lighting effect from a semi-indirect installation with special ceiling insert.

Fig. 12.— Showing installation of tungsten filament lamps and special curved white glass screens.

the passengers' eyes from the glare of the bare filament and also to reflect the light up to the ceiling. The particular advantage of this system of lighting was that it eliminated the necessity of reflectors, special holders and other accessory equipment; thus lowering both installation and maintenance costs. The illumination was fairly uniform (Fig. 3), though the uneven spacing necessitated by the car construction made it unnecessarily high at the center. As the entrance and exit doors were located here, however, this was no great objection. The average intensity was 7.7 foot-candles at normal and 5.1 at 85 per cent. voltage. The energy consumption was 1.69 watts per square foot, the effective lumens per watt 4.65, and the utilization efficiency 58.4 per cent. The appearance of the car lighted was pleasing. The lamps, being located on the center line of the car, did not interfere with the clear reading of advertising signs located along the sides.

No. 2.—In the second semi-indirect lighting test a novel equipment was used (Fig. 9). Ten 56-watt clear tungsten railway lamps were located on the center line of the ceiling, supplemented by 4 10-watt tungsten emergency lamps. Six inches (15.2 cm.) below the ceiling and extending the entire length of the car, was suspended a reflector consisting of a white enameled board 11 in. (28 cm.) wide, convex on a 16-in. (0.4 m.) radius. The bowls of the 56-watt lamps extended through holes cut in this reflector. Under each hole was fastened a white glass dish to diffuse the glare of the bare lamp filament. The spacing of the lamps is shown in Fig. 13. The plan in using this combination was to utilize as much as possible of the direct light from the lamp, to illuminate the advertising signs; the indirect light to give even distribution and the direct light to brighten up the under side of the reflectors. Distribution curves from this equipment are shown in Fig. 13. The light distribution was good, but the intensity low, averaging 3.9 foot-candles at normal and 2.2 at 85 per cent. voltage. The watts per square foot were 1.03; effective lumens per watt 3.81; and the effective utilization efficiency was 47.2 per cent. The resultant illumination was pleasant, but the appearance of the lighting equipment was rather crude, suggesting a watering trough down the center of the car. It was a curious fact that while both sides of the reflector and the ceiling

were painted alike, the under side of the reflector appeared grey, due to the lower intensity of light on it.

Another test was conducted on this same equipment with the interior finish of the car silver grey instead of white. This change lowered the effective utilization efficiency about 10 per cent.

The next semi-indirect equipment tested consisted of 10 94-watt tungsten railway lamps equipped with 5 13-in. (33 cm.) white glass bowls, mounted down the center line of the ceiling. There were 2 94-watt lamps and 1 10-watt emergency lamp in each bowl. (See Fig. 10). The bowls were hinged, allowing of lowering for cleaning and lamp replacement. The bowls were suspended with their tops located 12 in. below the center of the ceiling. The illumination from this system was very uneven, being high directly under the units and low between them (see Fig. 14). The average intensity was 5.7 and 3.2 foot-candles at normal and 85 per cent. voltage, respectively; watts per square foot 1.69; effective lumens per watt 3.36; and effective utilization efficiency 41.5 per cent.

In order to determine the effect of the shape of the ceiling on the light distribution, a special headlining consisting of a white enameled insert, having a 3 ft. (0.91 m.) span on an 18 in. (0.45 m.) radius, was inserted and the test repeated. Fig. 11 shows the appearance of the insert and illumination effect. This resulted in raising the average foot-candles to 6.1 and 3.4 at normal and 85 per cent. voltage, respectively; effective lumens per watt to 3.62; and the utilization efficiency to 44.7 per cent. The distribution curves of this equipment are shown in Fig. 15.

The insert was then removed and the test repeated with a different spacing of the units. This resulted in a little improvement in distribution. The principal trouble with this installation was that the headroom in the car was not sufficient to allow the lighting units to be hung the proper distance below the ceiling.

The next equipment tested required special reflecting devices. Ten 56-watt clear tungsten railway lamps were located in a single line down the center of the ceiling, with 5 10-watt all-frosted emergency lamps in rosettes between them. Each 56-watt lamp was equipped with a screen made from a circular piece of glass bent

over a cylinder (Fig. 12). This resulted in a screen 11 in. (27.9 cm.) long by 8 in. (20.3 cm.) wide by 3 in. (7.62 cm.) deep. When these screens were hung beneath the lamps with their open ends towards the sides of the car, it was impossible to see the lamp filaments from any part of the passenger car body; at the same time the direct light from a considerable portion of the lamp fell on the ceiling and reached the reading plane with but one reflection, making the system fairly efficient. The distribution lengthwise of the car was even, though the outboard seats received considerably less light than the center aisle of the car (Fig. 20). The average intensity was 4.8 and 2.7 foot-candles at normal and 85 per cent. voltage; the energy consumption 1.04 watts per square foot; effective lumens per watt 4.63; and effective utilization efficiency 57.6 per cent. The chief advantage of this equipment was the ease with which the reflectors could be cleaned. The appearance of the car lighted was rather pleasing.

TOTALLY INDIRECT TESTS.

No. 1.—The first totally indirect equipment tried consisted of 8 special indirect fixtures, these being white porcelain enameled on steel, 15½-in. (39. cm.) in diameter and 5½ in. (16. cm.) deep (Fig. 16). Each fixture contained 3 36-watt tungsten lamps mounted vertically. The fixtures were hung in a single row down the center line of the ceiling, the tops of the reflectors being 13 in. (33. cm.) below the ceiling. The spacing of the units is shown on Fig. 21. The resultant illumination was uniform and of fairly good intensity, averaging 5.1 and 3.2 foot-candles at normal and 85 per cent. voltage, for an energy consumption of 1.47 watts per square foot. The effective lumens per watt were 3.43 and the effective utilization efficiency was 46.3 per cent. The chief drawback of these fixtures was their liability to catch and collect much dirt, thus materially reducing their efficiency; also, to obtain good distribution it was necessary to hang them so low that they might be in the way of tall passengers.

No. 2.—In order to get away from a low fixture in the center line of the car, the next equipment tested consisted of 20 36-watt tungsten railway lamps in indirect reflectors. These were mounted

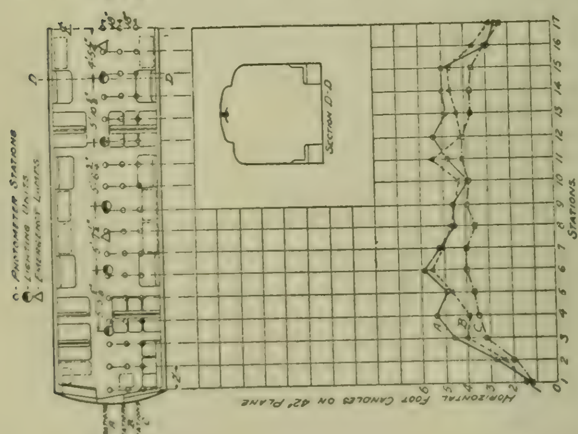

Fig. 13.—Light distribution from a semi-indirect installation consisting of ten 56-watt tungsten railway lamps in special convex reflector and four 10-watt emergency lamps. Installation shown in Fig. 9.

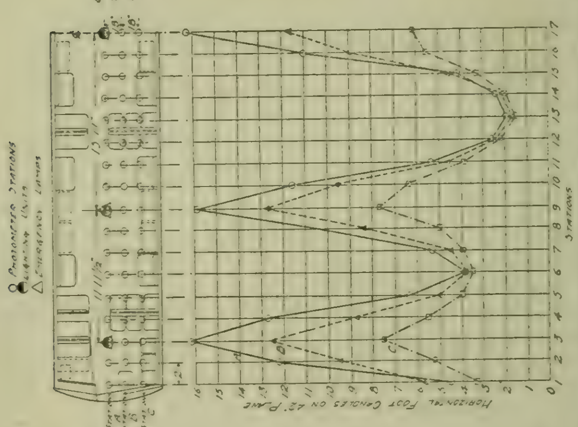

Fig. 14.—Light distribution from an installation of five semi-indirect units. Installation shown in Fig. 10.

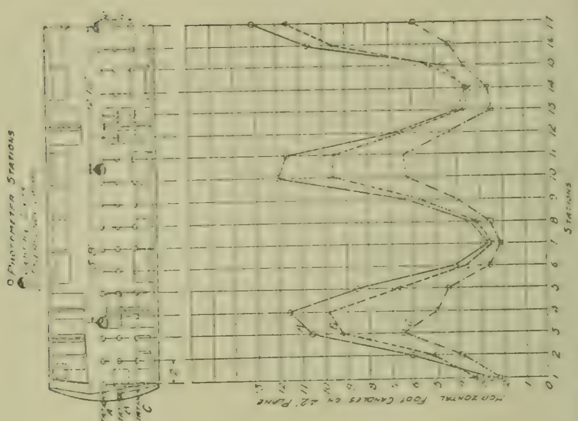

Fig. 15.—Light distribution from five semi-indirect units and ceiling insert. Installation shown in Fig. 11.

Fig. 16.—Installation of special indirect fixtures. Each fixture contains three 36-watt tungsten filament railway lamps. Light distribution shown in Fig. 15.

Fig. 17.—Special installation of indirect lighting. Reflectors set in coves, ten on each side. Ceiling rosettes for emergency lighting.

Fig. 18.—Indirect lighting from units on center stanchions and grab rails.

Fig. 19.—Lighting equipment finally adopted, consisting of fifteen 56-watt, bowl-frosted tungsten filament railway lamps in white glass reflectors, supplemented by six 10-watt, round bulb, all-frosted tungsten filament lamps for emergency lighting. Installation finally adopted.

in two rows of ten each on the sides of the car, just above the deck sill between the ventilators, as shown in Fig. 17. Five 10-watt frosted lamps in rosettes were mounted on the ceiling for emergency lamps. The 36-watt lamps were mounted horizontally with their centers 7 ft. 4 in. (2.25 cm.) above the floor. The spacing of the lighting units and the distribution therefrom is shown in Fig. 22. The resultant illumination was of low intensity, averaging 3.5 and 2.2 foot-candles at normal and 85 per cent. voltage. The wattage consumption was 1.32 per square foot; effective lumens per watt were 2.67; and effective utilization efficiency was 36.3 per cent. The main objection to this system was the problem of keeping the reflectors clean.

No. 3.—The last test was made on 12 94-watt tungsten railway lamps in indirect reflectors and 5 10-watt emergency lamps in rosettes, located down the center line of the ceiling. In order to get maximum headroom for these reflectors and still have them out of the way of passengers, special inverted cone-shaped containers for the reflectors were built into the stanchions along the center line of the car (Fig. 18). Unfortunately the construction of the car necessitated spacing the units rather far apart, so that uneven illumination resulted. In addition to the bowls, smaller inverted bowls were mounted on the horizontal grab rails, at points shown in Fig. 23. Each of these contained 1 94-watt tungsten lamp, making a total of 12 94-watt and 5 10-watt lamps in the car. The average foot-candles were 8.5 and 4.7 at normal and 85 per cent. voltage; watts per square foot 2.01; effective lumens per watt 4.21; and the utilization efficiency was 53.4 per cent. Considerable difficulty would be experienced in keeping this equipment clean and free from refuse.

The tables in the Appendix gives general summary of the tests.

IMPORTANT CONSIDERATIONS.

In studying the tests to choose the final method of lighting, the following condsiderations were carefully weighed:

General Effect and Appearance.—The general effect and appearance of each system under test were judged by comparison with present methods (in general) of car lighting for similar service, *i. e.*, with the use of tungsten lamps but without reflectors.

Under this item was also considered the effect of the distribution of light on the various parts of the car.

Lack of Eyestrain.—In comparing the various systems tested, the effect of the light on the eyes was particularly noted by a large number of observers.

Ease in Reading for Seated and Standing Passengers.—In comparing the three methods of lighting—direct, indirect and semi-indirect—particular attention was given to the possible shadows thrown on reading matter of seated passengers, by passengers standing in a crowded car. In some cases it was found that passengers could obtain proper light in any position; in others it was necessary for them to move in their seats, often to uncomfortable positions, to obtain proper light.

Efficiency of System.—The efficiencies of the various lighting systems tested differed widely. In some cases this was largely due to the type of reflector used; in others to the position of the reflector, shape of the ceiling, etc. In several tests it was evident that improvement could be made by changes. Should any one system meet with particular favor in all other respects, it was considered probable the efficiency could be raised by a more detailed study.

Maintenance.—The question of maintenance was serious. Some of the most desirable arrangements of reflectors and lights were handicapped by the dust problem. With a large number of small units this difficulty increases. Various methods of keeping reflectors and ceiling clean were considered.

Power Consumption.—In order to secure a reasonable operating cost, low power consumption was considered one of the important factors. The indirect system of lighting required considerably more power than the direct, while the semi-indirect came between these two.

Depreciation.—The relative loss of reflecting power, due to accumulation of dust on the various types of reflectors, was also given careful consideration.

Emergency Lighting.—It was decided that sufficient light would be obtained from the emergency lights to permit clearly distinguishing people and various objects in the car with main lamps extinguished.

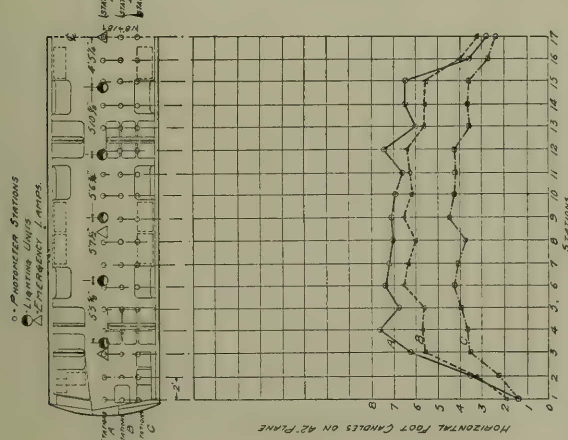

Fig. 20.—Light from ten 56-watt tungsten railway lamps in curved screens, and five 10-watt all frosted emergency lamps set in ceiling rosettes. Installation shown in Fig. 12.

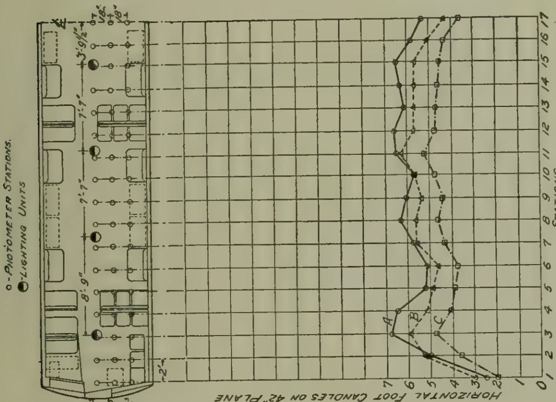

Fig. 21.—Light distribution from eight special indirect units. Installation shown in Fig. 16.

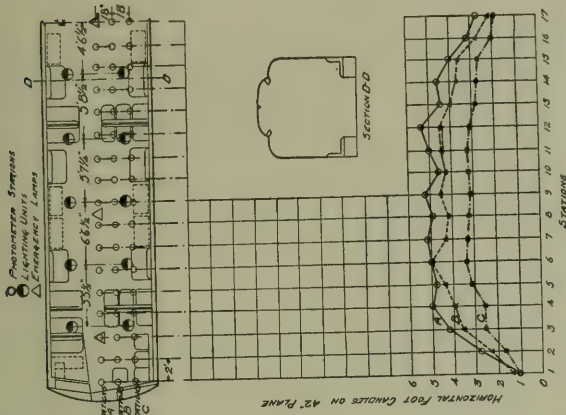

Fig. 22.—Light distribution curves obtained from the special installation of indirect illumination shown in Fig. 17

RESULTS.

A thorough study of all these conditions finally led to the adoption of a single line of 15 56-watt bowl-frosted tungsten railway lamps down the center line of the ceiling, equipped with reflectors as shown in Fig. 19, supplemented by 6 10-watt all-frosted round bulb tungsten emergency lamps. This system was chosen as the one containing the highest percentage of the desirable factors—satisfactory illumination, low power consumption, low maintenance and upkeep and pleasing appearance with the lamps both lighted and extinguished.

The spacing of the reflectors was arranged to be symmetrical. One unit was placed on each end bulkhead of the car to bring up the illumination at these points. The emergency lamps were placed in rosettes, one being located on the side wall over each pair of doors. These lamps do not burn while there is power on the line, but the instant that fails the emergency lamps are automatically thrown onto a storage battery.

Fig. 19 shows the interior of the car as finally equipped. The illumination averaged 5.94 foot-candles at normal and 3.85 at 85 per cent. voltage. The energy consumption was 1.44 watts per square foot; effective lumens per watt 4.14; and the utilization efficiency 50.6 per cent. These data are not comparable with the other tests, due to the use of bowl-frosted lamps (instead of clear), also a larger number and different arrangement of lighting units. Distribution curves are given in Fig. 24.

It was interesting to note that the low intensities of illumination, at stations 7 and 17 (Fig. 24), are opposite the entrance doors, which are dark green, in comparison to the white finish between doors. The curves were slightly high at stations 2, 3 and 4, due to the fact that the end lamps are located on the bulkheads considerably lower than the rest of the lamps in the car.

On the whole, the illumination is remarkably soft, even and pleasing. It is not possible to note any unevenness with the naked eye. The use of bowl-frosted lamps lowers the efficiency a little, but also eliminates glare, even when looking directly up at the lamp.

In addition to the general illumination there are other uses of lamps, in connection with the signal system, which may be of

interest. There is a series circuit going through a contact on each door in the car and on all doors in the train when more than one car is used. This circuit also goes through two 2-candle-power, 6-volt lamps located on top of the master controller near the motorman. When all doors are closed one of the lamps lights up and until this occurs it is impossible to start the train. Two lamps are used for safety. If one fails the other is thrown in

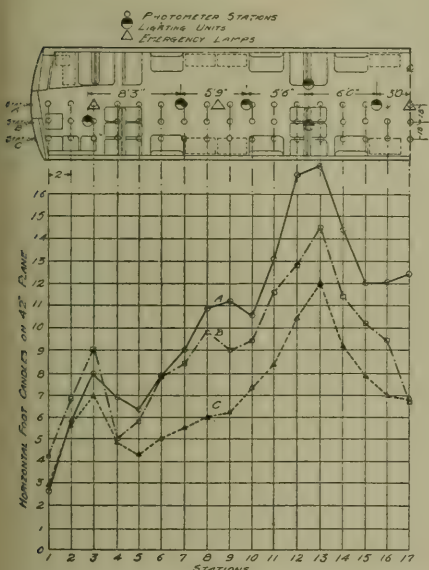

Fig. 23.—Light distribution curves obtained from the system of indirect illumination shown in Fig. 18. Construction of car necessitated spacing units rather far apart.

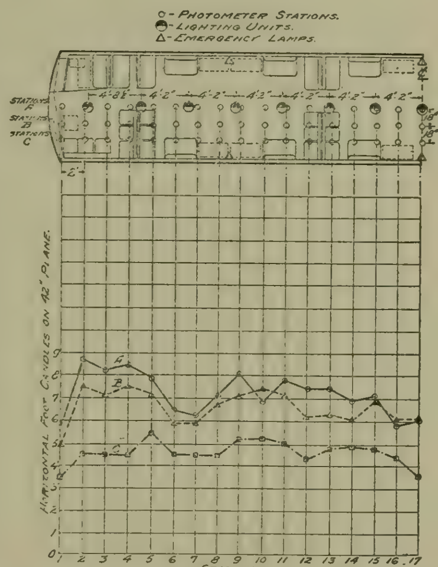

Fig. 24.—Light distribution from fifteen 56-watt bowl-frosted railway tungsten lamps in white glass reflectors, and six 10-watt frosted emergency in rosettes over side doors. Installation shown in Fig. 19. Equipment finally adopted.

circuit. The coupling of any number of cars together automatically arranges the circuits so that the lamps on the controllers, other than those on the two opposite ends of the train, do not burn.

Block signal lights are located in the cab, *i. e.*, instead of having the signals aside of or above the track, as is usual; the signal is located in the car in front of and slightly to the right of the controller. The signal consists of three lights—red, green and yellow—each containing a 32-volt tungsten filament lamp of about

10 watts capacity. It is planned to use double filaments in these lamps, so that when one fails the other will still be in operation. If the signal is set to stop and is not obeyed, within a certain distance, a warning whistle blows near the motorman, and if the signal remains unheeded a certain further distance, the brakes are automatically set. Coupling two or more cars together also cuts out the signals in the cabs other than the two on the ends of the train. A small 32-volt ½-candlepower tubular carbon lamp is also installed over each air gauge.

The end of each car carries two classification lamps, 10-watt, 34-volt, on the roof (Fig. 5). Colored screens are used in these to obtain the different destination indications. These lamps are also automatically cut out between cars where two or more are coupled together.

At the ends of each car, over the bumper, are located 4 10-watt, 40-volt, signal lamps back of lenses; one above the other—two on each side of the car. The upper is red and the lower white. On the front end the white ones only burn; on the rear the red only. Reversing the controller automatically changes these end indications. These lamps also are cut out between cars of a train.

APPENDIX.

Test No.	Lamps	Reflectors	Foot-candles[1]		Total watts	W/sq. ft.[2]	L/W[3]	Per cent. efficiency[4]
			Normal voltage	85 per cent. voltage				
1	10 56-watt	6-in. Sudan No. 01225	5.685	3.157	600	1.03	5.540	68.7
2	10 56-watt	Holophane XI-40	6.056	3.350	600	1.03	5.905	73.2
3	5 94-watt	Holophane XE-100	5.020	2.780	510	0.871	5.758	71.5
4	12 80-watt	None	7.695	5.144	990	1.692	4.649	58.4
5	10 56-watt	Doric dishes	3.908	2.170	600	1.03	3.810	47.2
6	10 94-watt	Pyro No. 1209	5.688	3.165	990	1.692	3.361	41.5
7	10 94-watt	Pyro No. 1209 (ceiling insert)	6.133	3.383	990	1.692	3.624	44.7
8	10 94-watt	Pyro No. 1209 (different spacing)	5.554	3.059	990	1.692	3.282	40.5
9	10 56-watt	Moonstone screens	4.834	2.680	610	1.042	4.635	57.6
10	24 36-watt	Alexolite	5.060	3.210	864	1.477	3.426	46.3
11	20 36-watt	E-60 National X-Ray in coves	3.514	2.230	770	1.316	2.670	36.3
12	12 94-watt	E-100 National X-Ray	8.463	4.700	1178	2.013	4.206	53.4
13	15 56-watt bowl-frosted Mazda[5]	6-in. Sudan No. 01225	5.94	3.85	840	1.44	4.14	50.6

[1] Average effective foot-candles on a horizontal plane 42 inches above the floor, in car body.
[2] Watts per square foot. [3] Effective lumens per watt. [4] Effective utilization efficiency. [5] Equipment finally adopted.

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DISCUSSION.

MR. T. W. ROLPH: The authors of this paper have presented us with some extremely valuable data, and we are fortunate in having this available for future use, in car lighting practise. There is an interesting point which I would like to bring out, and that is in regard to per cent. utilization efficiency obtained. I have a record of some car lighting tests, which were conducted by the Indianapolis Traction Terminal Company, in Indianapolis, in May of last year. There were recorded in a paper presented before the Pittsburgh section last November by Mr. L. C. Doane.† The efficiency obtained with a prismatic system, using 56-watt lamps, was 46.1; whereas with these tests the efficiency obtained was 73.2. Similarly with a unit of medium density opal,‡ the efficiency obtained in the Indianapolis test was 40.2; while the efficiency here is 68.7. This difference is due to the finish of the cars. We have obtained in the tests recorded here, probably the highest utilization efficiencies that have ever

† Modern Street Car Lighting, TRANS. I. E. S., vol. X, p. 82, (1915).
‡ "Sudan" glass.

been obtained in general commercial work. The subway people are to be congratulated on obtaining efficiencies very appreciably beyond those which have been obtained in other classes of lighting.

Mr. S. G. Hibben: To the companies which have made such a thorough investigation of car lighting in this instance, there is more than ordinary credit due, both for the standard and detail of the work, and also because a good deal of this car lighting is still pioneering. The engineers of this investigation and the authors of the paper deserve a large measure of thanks.

The night before last in Pittsburgh at a section meeting of the society certain men, who are supposed to know a great deal about car lighting equipment, made the statement that in several cars where the tungsten lamp had been tried in conjunction with globes, the illumination was poorer and of less amount than when bare unshaded carbon lamps were used. On looking into that pessimistic statement, I found that the experience of those particular men was that the lamps had been used in prismatic hemispheres against the ceilings of the cars. The comparative inefficiency of such glassware used thus, and its dustiness, was a very unfair argument against the general use of tungsten lamps and reflectors.

Some criticisms that have been made against the economy of tungsten lamps came from the fact that the lamps were stolen, and not broken, and that loss might be mentioned here in connection with the comparison between center-deck and side-deck lighting. I have experienced cases where lamps placed low along the side decks were stolen quite often. The lamps along the center deck were out of reach and did not disappear so fast. I believe these losses may be reduced through the use of the marine type socket or receptacle. The coiled spring into which the lamp base screws not only prevents the lamp from shaking out, but also prevents it from being easily unscrewed and stolen.

Concerning the glass reflectors, I want to call attention, in the first place, to the inadvisability of using any blown glass reflectors on which many manufacturers leave a ground or rough edge. On account of the method of manufacture, the blown reflectors in their first stage, are completely closed, and afterwards are

broken off at the bottom, and ground straight. If this roughed edge is not fire-polished, it in time will gather dirt and appear as a dark edge.

There is just one experience I have had in the failure from breakage of glass reflectors in car lighting service where, under very extreme conditions of rough service, several shades which were poorly held by the glass lip only, were broken around the upper part. The type of holder which has the inner flange will, of course, prevent that sort of breakage.

If the ceiling finish of the tested car as herein reported was polished or glossy, the results from the indirect or semi-indirect units might not be as good as in the case of depolished ceilings. Light from the curved-plate units especially would be directed against the sides of the car by specular ceiling reflection, and would be largely lost.

Regarding cleaning costs, I would like to get some more figures on that subject if there are any available. After a year or two, about the best data I have on hand shows an expense of about 7 cents to 10 cents per unit per month for cleaning expenses. That I believe involves wiping the reflector, dry, three times a month and washing it with water once a month. If the reflectors have any kind of crevices, as in the case of prisms, or if the elaboration is a design with horizontal lines, the expense of cleaning may be considerably greater.

These cars are I suppose arranged with three circuits of lamps. In case of one lamp failure the illumination is cut down to approximately two thirds of its former value, which still is, I believe, sufficiently high. To those unacquainted with some other practises, fifteen 36-watt lamps for a car are sometimes considered too many, and arrangements have been made with either two circuits of five lamps each, or one circuit of five larger lamps, and using a selector switch which will short-circuit a burned-out lamp, and simultaneously place in the circuit an auxiliary lamp. One good feature of this arrangement is that by using a three-point, or three-way switch, interurban cars which load and unload at definite stations can be lighted at both platforms or at either platform, while one regular unit in the center of the car would be temporarily cut out.

There is at least one other system of wiring with features of special interest, where there are ten 110-volt lamps in series, on a circuit of 1,100 or 1,200 volts. One of the peculiar features in this case, is that the large or mogul base lamps are necessary, because with the failure of one lamp the open circuit voltage across the base of this lamp would be that of the line, and would tend to arc over the distance separating the contact points of ordinary Edison base lamps.

Mr. G. H. Stickney: This paper presents a more complete and comprehensive set of car lighting data than has heretofore been available. The fact that the different lighting arrangements have been tried out in the same car and under the same conditions gives unusual value to the comparative results. In the past it has been impossible to eliminate variations due to difference in shape of cars, finishes, window areas, etc. We are certainly indebted to the New York Municipal Railway Corporation and Brooklyn Rapid Transit Company for giving out the information. I know they have hesitated to do so lest it work injury or injustice to excellent types of equipment which for their conditions were not so suitable as some other types. I believe this factor had something to do with the omission of more general conclusions. The practical conclusion of the tests is, of course, indicated by the lighting plan selected. The simple presentation of the facts, as given in this paper, is a pleasant contrast to some papers in which authors draw sweeping conclusions apparently not warranted by the data presented.

The effect of the light finish of cars, brought up by Mr. Rolph, is exceedingly important and often does not receive sufficient attention from railway companies. A light finish in the lower part of the car is not especially advantageous and is easily soiled. In the upper part, however, a light finish not only helps to economize the light, but adds to the diffusion and evenness of distribution.

One of the serious problems of applying the reflector method of car lighting was that of securing a satisfactory holder for the reflectors. The holder shown here to-night has more good features than any other I have seen. It has seemed objectionable to some to use the 2¼ in. fitter rather than the more common

2¼ in.; but, as both prismatic and white glass reflectors with this fitter are available, this would hardly seem to me serious; while the other advantages which can be obtained with the larger fitter would seem to me to be important. The holder clamps the reflector in such a way that it cannot possibly fall unless completely shattered. The glass is supported from below independent of the flange. The larger opening permits the use of stronger porcelains on the socket and therefore provides safer insulation. The large wiring space makes it more convenient and safer to wire with the heavily insulated cables required on street railway circuits.

A spring socket protects the lamp from excessive vibration. While this does not entirely prevent stealing of lamps, it renders their unauthorized removal more difficult.

Most of the lock-sockets with which I am familiar cannot be used with reflectors.

Very little trouble from stealing has been encountered as far as I am able to learn. Practically all lamps stolen are taken by employees when the cars are in the car houses. It would, therefore, seem that the best way of overcoming it would be through discipline of employees, just as in the case of an office or industrial establishment.

Mr. Frank M. Brinckerhoff: This paper gives very interesting details of the tests. One feature, always difficult to decide, is the commercial value of any lighting system. It is hard to place a value on the lighting of passenger cars, except as it affects the traffic of the road. If two car lighting methods are in use on the same train, it can easily be noted that the cars which are improperly lighted carry but few passengers as compared with cars which are better lighted, and one can thus possibly place a relative value on the lighting systems. The New York Municipal Railway cars are to be in the subway about one third of the entire time of their operation; therefore, the lighting problem is of considerable interest, during the day as well as during the night. Of course, with the ordinary trolley car, operating on the surface and requiring electric lights but a few hours of each day,

the lighting is of less importance than in subway service where it is an all-day proposition.

One possible commercial view that could be taken of the lighting problem is the effect on the advertising cards. Now, that may sound rather odd, but in a great many cars, especially in subway service, where the traffic is very heavy, the income from the rental of advertising space is very considerable. At times the cards and color effects are made very attractive to catch the attention of passengers. The advertiser is undoubtedly influenced by the lighting which is thrown on his advertisement.

CHAIRMAN: You will notice in all these cars that they all have full windows just as passenger coaches; it has always seemed to me a considerable waste of light to have the same windows in the cars that you would use with daylight cars. There seems to be no good reason why the sides of the cars should not be finished with white enamel and just a narrow window near the top of the present glass.

MR. FRANK M. BRINCKERHOFF: The reason for windows in subway cars is to enable the passengers to see out at the stations; so that passengers can see at what station they are. People frequently have trouble in determining their station. The seated passenger needs the window to look out just as much as the standing passenger does, and you will find the windows of the subway car about suitable for the purpose.

All the ceilings have been rubbed flat finish to take off the high gloss; this surface eliminates a great deal of glitter and affords a much more pleasing illumination.

CHAIRMAN: Peculiar color combinations are used on the subway advertising cards; yellow and orange are used in certain words or lines for emphasis. Has an advertiser ever complained that these cards are not as conspicuous under artificial light as he thinks they should be? These cards are probably designed and approved under daylight, and it cannot be expected that certain color combinations will be as striking under artificial light as they would be in daylight.

MR. FRANK M. BRINCKERHOFF: I do not think the color of a card has ever been discussed, but the color of the car finish has. I have never heard of a complaint by an advertiser that his pecu-

liar color combination was not properly illuminated; I do not think that I have ever heard of that being brought up; but, of course, the color combination of the car itself has a great deal of effect, or rather it influences the appearance of the cards. A good frame around a picture brings out and enhances the picture; just so, this moulding around the advertising card either produces an attractive effect, or detracts from the appearance of the cards. For example, if green moulding is carried along beneath the entire row of advertising cards, it gives it a dignity and balance that is rather attractive. If advertising cards are mounted against a flat white background above and below, it rather detracts from their color scheme. I have never heard of the color of the card being affected by the illumination; but I can easily see that it could do so.

Mr. Young: As to the elaboration on the glass to be used, I think every one is coming more and more to an absolutely plain surface on any lighting glassware that they use. It is quite easy to get up a line of glassware comprising reflectors, hemispheres, etc., with an elaboration that is quite intricate; but it is quite hard to get up a piece of glass with a simple elaboration. I have been at it a good many years, and I know what it means. Recently, there has been marketed a line, as you would say, of absolutely plain glassware as shown in Fig. 12. The disk, or fixture shown is without elaboration. There has been some discussion to-night in regard to the collection of dust on reflectors, etc. The glassware shown in Fig. 12 could be more easily cleaned than a shade; the glass can be cleaned with a piece of chamois; or it can be cleaned with a dry rag, provided the atmosphere is not greasy; in which case, of course, the glass would collect grease and would have to be washed.

Mr. L. C. Porter (In reply): One speaker asked what factors were against the special turnip-shaped lamps without reflectors, and against the indirect system. One of the chief drawbacks of these two systems was the lack of headroom in a car either to get an indirect fixture or a special lamp with opal on the bottom sufficiently low from the ceiling so that it would light the ceiling fairly evenly, instead of just throwing a little spot of light on the ceiling. To do this it was necessary to put the lamp

or fixture so far down that it would necessarily be in the way of tall passengers, particularly those wearing opera hats. One of the other chief factors against those two systems was the collection of dirt, etc.

In regard to light distribution, it is true that the outside distribution curve is probably the most important one, but even with passengers facing sideways in the car it was found that, under average conditions, they held their papers at least two feet out from the side of the car, which brought them within the range of the distribution curve shown.

You will note that so far car lighting problems have dealt with fitting the lighting to cars at present in service—that is, cars already designed.

In one of the tests described in the paper, you will find that a special ceiling insert was made to see if the lighting could be improved. This opens quite a field; in other words, why should not the roof of the car be designed to fit the lighting?

Mr. Frank M. Brinckerhoff: If a car could be designed with a cross section similar to that headlight that we have looked at this evening, it would insure the most even distribution of light; in other words, if the roof of the car could be given a parabolic form and the lamps could be placed on the exact focal center of the parabola, an absolutely even distribution of light over the entire width of the car could be obtained. The height of the New York Municipal Railway cars made it necessary to take a certain definite width, with the result that it is impossible to place the light sources exactly as we would have desired; it was necessary to accept a compromise position. The distribution of light finally secured is about as good as can be obtained in a car of this height and width.

ADDITIONAL EXPERIMENTS ON COLORED ABSORBING SOLUTIONS FOR USE IN HETEROCHROMATIC PHOTOMETRY.*

BY HERBERT E. IVES AND EDWIN F. KINGSBURY.

Synopsis: This paper is a continuation of one recently presented under a similar title. It describes a blue solution which used over a standard carbon lamp duplicates the color of lamps of higher efficiency. The photometric calibration of this solution is given. Simple equations have been developed to represent the transmission of both this new solution and the previously described yellow solution.

In a previous paper[1] before the Illuminating Engineering Society we have described a yellow absorbing solution which can be used in varying concentrations to eliminate the difference in color between black bodies at different temperatures. We present herewith an account of a blue solution of similar properties, which may be used over the present carbon incandescent standards, to produce with them all the incandescent lamp colors up to the most efficient lamps now obtainable. In the previous paper details are given as to the mode of use of the solutions and upon the method of calibration. The present communication may be considered as a continuation of the other, containing only matter not therein included.

Constitution of New Blue Solution.—The blue solution has the following composition:

Nickel ammonium sulphate..............	50 gr.
Ammonium sulphate	10 gr.
Ammonia 0.90 gr.	55 cc.
Water to	1 liter of solution

Dilute with water containing 10 gr. ammonium sulphate per liter.

The solution should be used as fresh as possible, because on standing it slowly dissolves the glass of the containing vessel, and

* A paper read at a meeting of the Philadelphia Section of the Illuminating Engineering Society, March 19, 1915.

[1] Ives and Kingsbury, Experiments with Colored Absorbing Solutions for Use in Heterochromatic Photometry; TRANS, I. E. S., vol. VIII (1914), p. 795.

because alkaline solutions such as this are inherently less stable than acid solutions like the yellow one.

Calibration.—The same method of calibration was used as before. One advance lay in the fact that our average observer was obtained from the mean of sixty-one instead of twenty-five, as in the earlier work. The working group from whom the seven observers were taken was only in part the same as before, but, if the method of selection is reliable, their mean result should be the same as that of the similarly selected group used in the yellow solution work, since the mean value for the test green light was little affected by the inclusion of the larger number of observers now used in establishing the standard eye.

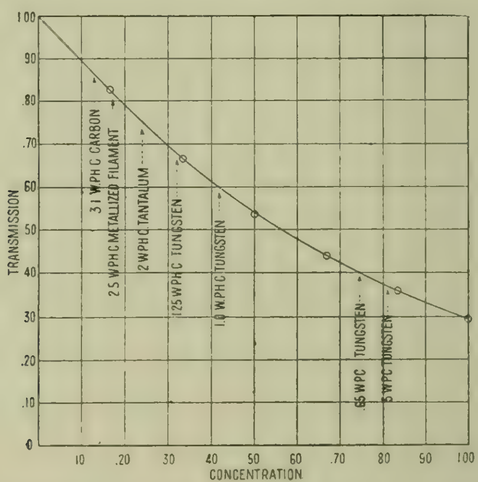


Fig. 1.—Transmission of blue solution. Equation of curve: $\log_{10}T = -.539C^{1.03}$.

The observations are plotted in Fig. 1, on which are also shown the approximate concentrations called for by typical illuminants.

Temperature Coefficient.—An undesirable feature of the yellow absorbing solution is the existence of a pronounced temperature coefficient, making it imperative either to work at the temperature used in calibrating or to apply corrections.

We find the blue solution to have practically no temperature coefficient over the range of temperature to be expected in the laboratory This is a very fortunate thing, especially as the field

of usefulness of the blue solution may be expected to be much greater than that of the yellow.

Spectral Transmission.—Fig. 2 shows the transmission through the spectrum, as measured on the spectrophotometer, for the 100 per cent. solution. When plotted in terms of log. absorption against $1/\lambda$ an approximation only to a straight line results, as with the yellow solution. This means that the color match obtained by using the solution is a subjective one and will not hold absolutely with observers of abnormal color vision. This divergence from actual identity of the two compared spectra is, however, too small, we believe, to cause trouble in practical work. We find as well that Beer's law does not hold, so that the concentration

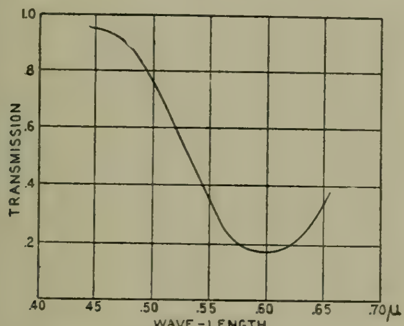


Fig. 2.—Spectral transmission of 100 per cent. blue solution.

necessary for any particular case cannot be obtained by experiments on thickness. Trial of various concentrations is necessary.

Comparison of Results Using Yellow and Blue Solutions.—The yellow solution when used on the test side performs the same color difference eliminating function as the blue solution on the comparison lamp side.

It is a matter of interest to know how closely the value to be assigned by using one solution agrees with that from the other. This constitutes a test of the method of calibration. If the method is reliable and self-consistent the same value should be obtained upon measuring a high efficiency lamp by the use of either solution.

This point was tested by the measurement of a type "C" tungsten lamp, efficiency 0.65 w. p. c., against a 4-watt standard. The

requisite concentration of the yellow solution was determined by the use of the wedge cells described in the previous paper; that of the blue by several trials. The relative intensity of the two lamps was then found to be the same to about ½ per cent. or within the errors of photometric setting.

This test, involving as it does two different series of measurements made several months apart, with largely different groups of observers, shows clearly the reliability of the photometric procedure.

Mathematical Expressions for the Transmission Curves.—In order that these colored solutions may not only be made up but also used from written specifications, it is desirable that their transmission be expressible in some simple mathematical form. This we find to be possible.

In the case of monochromatic light the equation connecting transmission with concentration is of quite simple form, namely,

$$T = T_0 e^{ac}$$

where T is transmission, T_0 is the transmission for zero concentration, e is the base of the natural system of logarithms, a is a constant and c is concentration. In the present case T_0 is unity, so that the relationship may be written simply:

$$T = k^c$$

or

$$\log T = ck'$$

Now, we are not dealing here with monochromatic light, but it is well known that over considerable ranges of color change in black body illuminants the total change in intensity is very closely the same as the change of intensity for a certain single wavelength.[2] We should, therefore, expect the above equation to hold over a fairly large range of concentrations. When, however, this range is exceeded the deviation is slow and can be taken care of by a slight modification of the simple law. Thus we find that over the whole range of concentrations called for by the present practical illuminants the transmissions of our solutions are represented with extreme accuracy by equations of the form

$$\log T = c^x k$$

[2] Ives, H. E., Note on Crova's Method of Heterochromatic Photometry; *Physical Review*, XXXII, 3, Mar. 1911, p. 316.

where x is a number only slightly differing from unity. The actual equations for the yellow and blue solutions are as follows:

Blue solution on comparison lamp side . . . $\log_{10} T = -0.539c^{1.03}$

Yellow solution on comparison lamp side . $\log_{10} T = -0.245c^{0.9}$

Yellow solution on test lamp side . . . . $\log_{10} T = +0.366c^{1.05}$

where T and c are expressed in decimal fractions of unity (*i. e.*, 20 per cent. transmission or concentration is expressed as 0.20). The curves represented by these equations lie everywhere distant

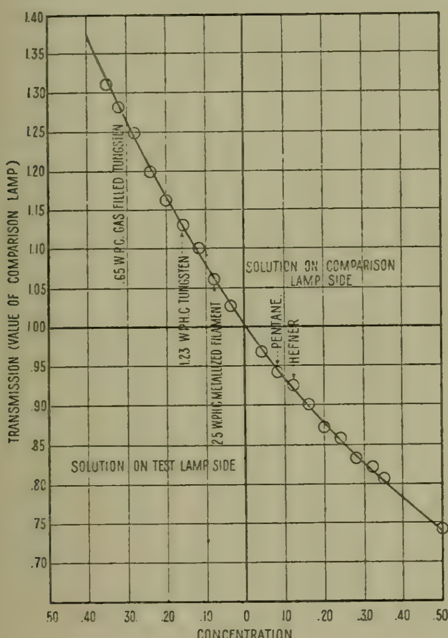


Fig. 3.—Transmission of yellow absorbing solution at 20 deg. C. Equations of curve: comparison lamp side, $\log_{10}T = -0.245C^{.9}$; test lamp side, $\log_{10}T = 0.366C^{1.06}$.

from the experimentally determined points by no more than the uncertainty of the experimental work. The full line in Fig. 1 has been drawn with the aid of the first equation, and in Fig. 3 the data on the yellow solution have been reproduced along with the curves represented by the second and third equations.

DISCUSSION.

In the previous paper we dealt rather insistently on the difficulties of working with absorbing solutions. Among these diffi-

culties the care of the glass tanks and the complications caused by the temperature coefficient figured prominently. In the light of our more extended experience we now feel it permissible to speak somewhat more favorably of this method. We have found that the absorbing tanks in the form developed in the course of the investigation maintain their similarity in spite of nearly continuous use for months. The new blue solution with its freedom from temperature coefficient removes another objection. And, finally, the possibility of representing the transmissions by simple equations places these solutions squarely in the category of primary color standards, entirely reproducible from specification at any time or place. By their careful use all laboratories can insure a high degree of uniformity and agreement in measurements involving the commonest type of color differences, once agreement has been reached on the values to be assigned to the transmissions. The scale upon which we have determined these transmissions is based upon a careful study of photometric methods and is, we believe, entitled to most serious consideration for adoption as standard.

A METHOD OF CORRECTING ABNORMAL COLOR VISION AND ITS APPLICATION TO THE FLICKER PHOTOMETER.*

BY HERBERT E. IVES AND E. F. KINGSBURY.

Synopsis: A study is made of the manner in which the spectral luminosity curves of individuals differ. It is pointed out that when the flicker photometer is used any observer can be corrected to normal by the interposition of the proper absorbing medium over his eye. Practical approximations to such absorbing media are developed and tried. By their means color-blind observers are made to read substantially the same as normal.

Various investigations on the spectral luminosity curves of individuals of normal and abnormal color vision have clearly established that these curves differ from individual to individual. The differences are small between those who would be classed as of normal vision, but of increasing magnitude as observers are included of the various types of recognized color blindness. This fact is illustrated by the luminosity curves of normal and color-blind observers shown in Fig. 1.

Now, an individual of abnormal color vision suffers from two characteristic disabilities, both probably due to the same fundamental defect. One is the distortion of color values, the other the distortion of luminosity values. These two disabilities are of differing gravity to an individual, depending upon the use he makes of his eyes. If his work demands the discrimination or harmonizing of colors, then inability to differentiate hues is sufficient to disqualify him. If, however, his work involves the measurement of luminous intensity the fact that one color has to his eye the same quality as another embarrasses him not at all, but the fact that the different colors do not have the same relative intensity as to a normal eye is a serious handicap.

One of the present writers suggested some time ago[1] that an abnormal eye might be corrected for purposes of photometry by

* A paper read at a meeting of the Philadelphia Section of the Illuminating Engineering Society, March 19, 1915.

[1] Ives, Discussion of a paper by Fabry; TRANS. I. E. S., June, 1913, p. 320.

the aid of an absorbing screen which would reduce the intensity of certain portions of the spectrum. Dr. Louis Bell more recently[2] has suggested that in certain types of abnormal color vision, where one sensation is only partly deficient, correcting glasses might, in restoring the balance between the different parts of the spectrum, enable the wearer to see colors in their normal hue relationships. This latter possibility of course only applies where all three fundamental sensations (in the Young-Helmholtz sense) are present to some degree. The photometric possibility is equally good whether the observer perceives color or not, provided he sees *something* in all parts of the normally visible spectrum. That is, even an individual who sees the spectrum as

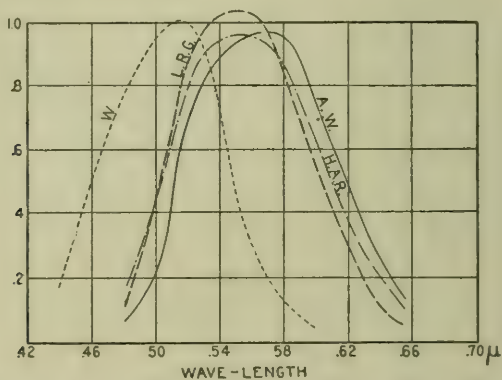


Fig. 1.—Spectral luminosity curves of three normal and one totally color-blind observers. (Three "normal" from data of Ives; color-blind from measurements by Bender.)

a mere colorless band should be able to obtain normal photometric results once the luminosity curve of his spectrum is normalized.

The type of observer just mentioned would in fact have a certain advantage in ordinary direct comparison photometry, because he would not be distracted by the difference of quality which causes the fundamental difficulty in colored light photometry. So serious is this distraction that definite and satisfactory results can be obtained in colored light photometry only by the use of the flicker photometer. Consequently in this paper,

[2] Bell, L., Types of Abnormal Color Vision; *Proc. Amer. Acad.*, 50, pp. 3-13, May, 1914.

which deals chiefly with the application of this correction method to photometry, the flicker method alone will be considered, it being understood that the method of correction should be equally applicable to direct comparison photometry were this latter a practical means of precision measurement.

The peculiar applicability of the flicker photometer to this proposed method of correction lies in its entire elimination of the question of *quality*. The system composed of the flicker photometer and the eye is a physical null instrument, in which the eye acts merely as the sensitive detector of a lack of balance in which color or quality plays no part and only the luminosity differences remain. Such a system may be subjected to the action of colored absorbing media in exactly the same way as can a thermopile or a photo-electric cell, with a similar alteration of its spectral sensibility curve.

Once this fact is clearly recognized the possibility of altering a known individual luminosity curve into a normal one by appropriate colored absorbing media is obvious. It is, however, possible that the production of a correcting screen for each individual might be a task of great difficulty. How much do individuals differ? Can an average type of correction be worked out practically? If so what is its field of successful application? These questions were the object of the investigation here reported.

I.—THE DIFFERENCES BETWEEN INDIVIDUAL LUMINOSITY CURVES AND THE CORRECTIONS CALLED FOR.

Some forty spectral luminosity curves, obtained by the flicker method, are available for study, obtained by Ives and by Nutting, and probably half as many more, obtained under somewhat different conditions by workers with the Lummer-Pringsheim flicker photometer. For the present purpose a single group is sufficient, and for this the curves obtained by Ives are used; Nutting's lead to exactly similar conclusions, as do probably also the other curves quoted. In Fig. 1 are shown several luminosity curves selected from the larger group of 18[3]. In Fig. 2 these are plotted in percentages of the mean at each wave-length. From

[3] Ives, The Spectral Luminosity Curves of the Average Eye; *Phil. Mag.*, Dec. 1912, p. 859.

these selected curves it is apparent that deviations from the mean are of two kinds: First, that characterized by a uniformly changing deviation of the type represented by the equation $I = \frac{A}{\lambda} + B$, and, second, small localized variations from this simple type of variation, resulting in more or less extended con-

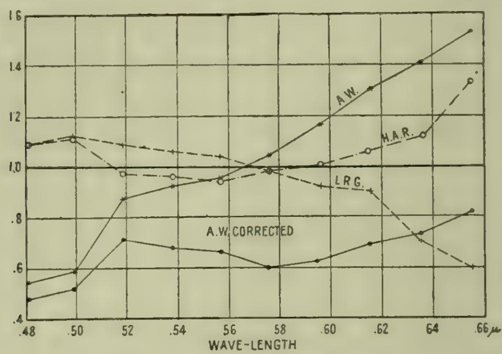


Fig. 2.—Characteristic deviations from normal spectral luminosity curve, and effect of applying correcting medium.

cavities or convexities in the plotted lines. These latter, which are in most cases undoubtedly real and not errors of observation, are due probably to individual differences of pigmentation of the fovea and similar causes, superposed on the main basis of difference, namely the relatively different proportion of the three color sensations. In Fig. 3 we have plotted the average deviation

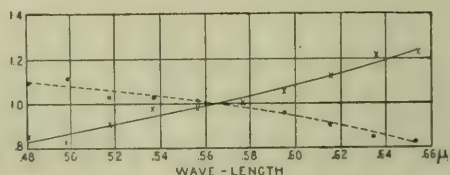


Fig. 3.—Average deviation from normal luminosity curve of red-sensitive and blue-sensitive groups.

from normal of all those observers lying clearly on the blue side of the mean and all those lying clearly on the red side. It is at once seen that the small localized irregularities are largely ironed out and that the average type of deviation from normal consists

in the simple gradual variation with wave-length represented by the equation already given.

It may be stated without further discussion that an average type of corecting medium would be one whose spectral transmission is the reciprocal of the average deviation just shown, as $T = \frac{a}{\lambda} + b$. Such a medium with varying values of a and b should correct the main deviation from normal vision. At the same time such an average correction cannot fit the smaller individual diifferences.

At this point it may be remarked that this study might have been carried through on merely one or two individuals whose luminosity curve would first be accurately determined, exact correction screens then being developed, and their performance examined. We have not done this because the well established physical characteristics of the flicker photometer already mentioned tell us in advance that such an individually worked out correction would be exact. The labor, however, of working out individual screens for every member of a laboratory staff would make the scheme at once a dubiously practical one. Our interest has, therefore, been in studying the possibility of adapting this method in such simplified form as to make it practical. We have accordingly worked out an average correcting medium and have investigated the extent of its usefulness.

II.—THE PERMANENCE OF THE COLOR CHARACTERISTICS OF INDIVIDUAL OBSERVERS.

Will a correction once found adequate always be so? This of course depends upon the permanency of the luminosity curve. In previous papers on the flicker photometer, evidence has been presented that an observer's characteristics are permanent. In the course of nearly a year's continuous use of the photometric method advocated by us, we have accumulated a mass of data from which very definite information on this point is available.

We have arranged some of these data graphically in Fig. 4. At our disposal were the following sets of observations: two series of readings on monochromatic green light compared with

the light of a "4-watt" lamp[4]; four series of measurements on a special yellow solution which in varying concentrations takes up the color differences between incandescent lamps of various efficiences[5]; two series on a blue solution of similar characteristics[6], which ultimately proved unsatisfactory (A) and two on the satifactory solution (B); two sets on a pair of test colors used in the selection of groups of observers for colored light photometry.[7] These are plotted in such manner that measurements on the blue side of the normal fall above the axis of abscissa, those on the

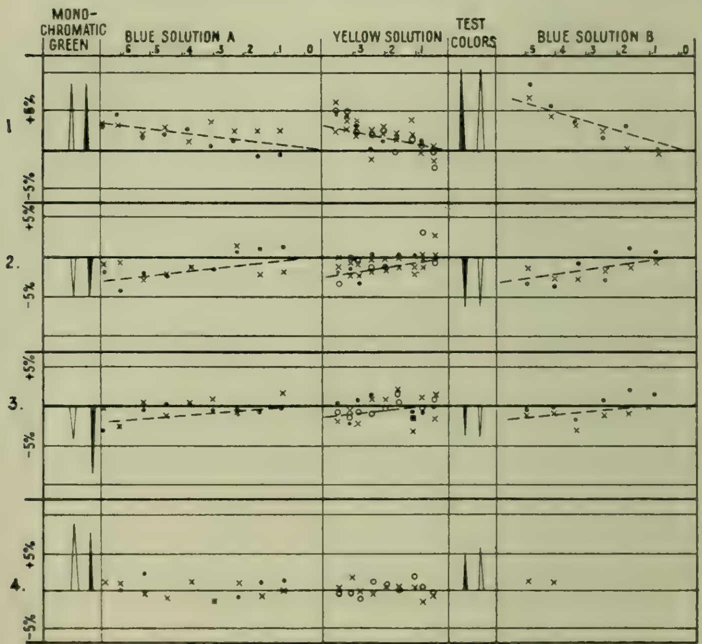


Fig. 4.—Photometric history of four observers.

yellow below. The ordinates are the percentage deviations from the mean. In the case of the yellow and blue solutions the

[4] Ives and Kingsbury, Measurements with the Flicker Photometer on a Monochromatic Green Solution; *Physical Review*, March, 1915, p. 230.

[5] Ives and Kingsbury, Experiments with Colored Absorbing Solutions for Use in Heterochromatic Photometry; TRANS. I. E. S., vol. VIII, p. 795; 1914.

[6] Ives and Kingsbury, Additional Experiments on Colored Absorbing Solutions for Use in Heterochromatic Photometry; TRANS. I. E. S., 1915.

[7] Ives and Kingsbury, On the Choice of a Group of Observers for Heterochromatic Measurements; TRANS. I. E. S., 1915.

greatest color difference is to the left, decreasing to a very small color difference at the right. The observations on these solutions should, therefore, in general converge toward the axis, as they do. The scattering of these points is not to be taken as evidence of lack of sensibility of the photometric method, as all kinds of possible errors influence the results.

With very few exceptions our observers have maintained throughout their positions relative to the mean. This is strikingly shown in the case of observers 1, 2 and 3, whose observations practically all fall on one side of the normal line. We have found but one actual reversal of position in the case of the monochromatic green reading by an observer, not here shown. The first reading was made upon a green absorbing solution which afterwards proved of unstable composition so that even this case is not clearly proven. Fluctuations of color vision do however undoubtedly occur, caused for instance by exposure to the eyes to intense light, by working with colored light, as in the spectrophotometer, etc., and these show up, as they should, in the flicker photometer measurements. But apart from these there is no doubt that an individual's spectral luminosity curve is as much a personal characteristic as, for instance, the configuration of the eye-ball, for which we prescribe spectacles.

An interesting piece of information is obtained by studying the relative amounts of the deviations from normal with the different kinds of color differences. These are not entirely parallel with different observers. Thus the percentage deviation from the mean of observer 4 is, with the very saturated colors of the first and last columns, quite large, but with the less saturated colors of the middle columns his readings average very near normal. On the other hand the more extreme observers, such as numbers 1 and 2, show up consistently away from the mean, although measuring the monochromatic green no further off than observer 4. These differences are clear cases of those localized differences in the luminosity curves already noticed. We may from them expect that no average type of correction will cut finely enough to take up with great success rather small differences in color vision, or do more with abnormal observers than bring them *near* normal.

III.—THE PRACTICAL DEVELOPMENT OF CORRECTING MEANS APPLICALBLE TO THE AVERAGE TYPE OF DEVIATION FROM NORMAL.

The absorbing media which we sought, to be used over the eye for correcting the luminosity curve, were two, a generally blue one, and a generally yellow one, each having a transmission represented by a straight line from one end of the visible spectrum to the other, and capable in varying concentrations of giving all ordinarily necessary corrections without serious departure from that type of transmission. Of course the exact attain-

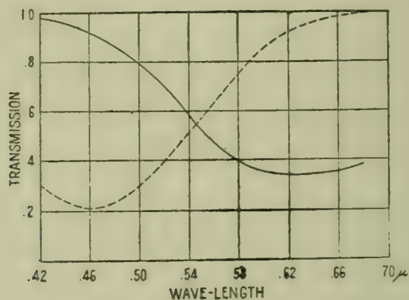


Fig. 5.—Spectral transmission of correcting solutions; full line, blue solution, dashed line, yellow solution.

ment of the desired characteristics is hardly to be expected. The media which we finally selected after considerable experimentation are for the blue:

Cupric sulphate .... 2.0 gr.
Ammonia (0.90 gravity) .... 200 cc.
Add water to make 1 liter of solution. (Dilute with water 4 parts, ammonia 1 part.)

and for the yellow:

Bayer's Fast Brown, 0.025 gram per liter of water.

The spectral transmissions of these are shown for 100 per cent. concentration in thickness of 5 mm. in Fig. 5. It will be seen that they approximate fairly closely to the required characteristics, especially through the middle, of the more important part of the spectrum.

The result of applying the 60 per cent. solution to the luminosity curve A. W. of Fig. 1 is given in Fig. 2. By the use of the correction the general slope of the curve is removed, whereby

it is reduced to the same class as those possessing merely localized irregularities.

The practical means for applying the correction consisted of small glass tanks, made very simply by drilling one centimeter diameter holes in pieces of plate glass 5 mm. thick and two and one-half centimeters square, filing a groove for filling and fastening thin glass faces on with paraffin. These were slipped over the eye-piece of the flicker photometer.

We have worked with liquid solutions as simpler for the experimental work. Doubtless colored glasses could be found which would serve. These could be used in the form of wedges.

IV.—THE EFFICACY OF THE CORRECTING SCHEME ON A GIVEN COLOR DIFFERENCE.

In order to determine the amount of correction needed by the various observers at our disposal, we have made use of the test

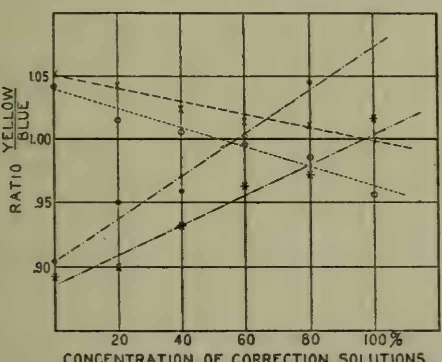


Fig. 6.—Effect of color vision correcting solutions on test color intensity ratio with four observers.

colors by which we select a group of observers for heterochromatic measurements[7].

Each observer measured the ratio of these two colors, which should measure equal to a normal eye, then with progressively greater concentrations of the correcting solution which was indicated as necessary. With each concentration a different ratio of the two intensities was obtained. The series of points thus found were then joined by a line the intersection of which with the axis indicated that exact correction demanded. These lines were found fortunately to be straight. In Fig. 6 are plotted the results ob-

tained by four observers. It is evident that in the case of a given color difference the method of correction is perfectly definite.

An interesting fact, in accordance with the known types of differences in the luminosity curves, is that individuals who measure the test colors nearly alike do not take the same correction. This is exhibited by the two red-sensitive observers of Fig. 6. One evidently has a much narrower luminosity curve than the other, for the correction is much less, and it is obvious that a monochromatic luminosity "curve" would not respond to the connecting scheme at all.

Before going on to the case of other color differences we may point out that in cases where a definite type of color difference is to be measured repeatedly a correction determined in this way makes it possible for any member of a laboratory force to make normal measurements. Thus a correction determined for the difference between standard and high efficiency incandescent lamps would work for all lamps of the same relative efficiencies and, what is more, it may be expected to work for all smaller differences of the same type, as those between lamps differing less in efficiency.

V.—TEST OF THE CORRECTING SCHEME ON OTHER COLOR DIFFERENCES.

While this development opens up a number of interesting possibilities we have been interested in pushing the question still farther. Will a correction determined from our test colors, be correct for other types of color differences? To obtain an answer to this question we have tried our various observers with their eye correctors on a commonly met color difference, namely, that between the standard "4-watt" carbon lamp, and a type "C" tungsten lamp at 0.65 w. p. c. We were specially fortunate in securing the cooperation of one observer who was known to be color-blind, and of one other, who from our previous work we knew to be rather far from normal in the opposite direction to the individual just mentioned. The first observer required a 300 per cent. concentration of the yellow correcting solution[8], the second a 150 per cent. concentration of the blue correcting solu-

[8] Working backward from the transmission curve of the correction solution required, we find that the luminosity curve of this observer is closely that of the totally color-blind, as shown in Fig. 1.

tion, as against a maximum of 100 per cent. for any of our other observers.

The results are shown graphically in Fig. 7. To the left are the relative values of the two lamps, in arbitrary units, as measured by the nine observers without the correcting device. To the right are shown the relative values as obtained by the corrected eyes, the dashed line through the middle is the true relative value of the lamps. It is seen at once that all the observers, color-blind and normal, have been brought quite close together and

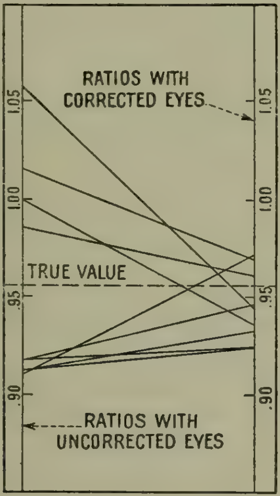


Fig. 7.—Results, with nine observers, of applying correction calculated from test color measurements to the color difference of 4-w. p. c. carbon lamp and 0.65-w. p. c. tungsten lamp.

every observer, without exception, has been brought nearer to the true value. An extreme variation of 15 per cent. has been reduced to five. Broadly, therefore, the corrections determined from the color difference represented by the two test colors serves for the new color difference.

Upon examination, however, it will be evident that while the improvement with the more abnormal observers is striking, the ones initially nearer normal have not all profited equally. We have cases of under-correction and cases of over-correction. The corrected points do not lie within 1 per cent. of each other as they should if the correction were perfect. This is exactly what

we had anticipated from the preliminary study of the luminosity curves. No average correction can be expected to fit the smaller differences. We have decided from our work that if an observer measures the test colors off by less than 5 per cent. that there is no object in applying this correcting medium for general work, for his deviation from normal in all probability consists in local irregularities of the spectrum luminosity curve not to be overcome by an average correction.

The correcting scheme does not, therefore, as we have worked it out, obviate the necessity for selecting a group of individuals for making general heterochromatic measurements, as it would do were the correction exact for each individual. We can, however, modify our requirement for five or more observers whose mean value of the test colors is *naturally* correct, into a requirement of five or more *corrected observers.*

SUMMARY.

A method for correcting the spectrum luminosity curve of an abnormal or color-blind eye has been developed. By a practical application of this method to the flicker photometer it is possible to (1) equip any observer so that he will read correctly color differences of a given type; (2) equip a color-blind observer so that he will not only read correctly color differences of a given type, but also measure other color differences no farther from correct than a random observer of "normal" vision will do.

The account we have given here is concerned chiefly with the experimental study of the eye correcting scheme. The means developed, involving the use of liquids in glass tanks, are experimental laboratory means. We believe it to be possible to reduce the results of the work to a more practical form for general use by the use of special glasses. Such practical development may be reported upon later.

INCANDESCENT HEADLIGHTS AND PROJECTORS.*

BY P. S. BAILEY.

Synopsis: This paper is intended to outline the commercial development of incandescent headlights and projectors. It gives a brief description of the manufacture, application and operation of various types of headlights.

The appearance of the gas-filled tungsten lamp with a focus-type filament, in commercial form, has stimulated the design of several devices for the projection of light from an incandescent source. The field for apparatus of this description appears to be very broad. Aside from its application to the stereopticon and to street railway requirements, there is an active tendency among the steam railroads to adopt the incandescent head-lamp. In addition, there is apparently a considerable opportunity for the incandescent projector in marine work, such as in the equipment of tow-boats, launches, and other small craft, to enable the pilots to locate buoys, landing places, etc. Then, too, there is display lighting, involving the illumination of flags and decorations, public buildings, signs and the advertisement of seashore resorts. And lastly, in the case of war, for military and naval operations. Searchlights are being employed in Europe in the present hostilities, as an aid in the digging of trenches, picking up the wounded, burying the dead, detecting aeroplanes, blinding a charging enemy, and assisting in attack.

The high powered arc searchlights with the necessary engines, motors and generators or storage batteries to operate them, are extremely heavy and cumbersome. For this reason, the incandescent projector, operated from a portable gasoline electric set would appear attractive and worthy of the consideration of military representatives.

Problems concerning the lighting of thoroughfares and interiors of practically all descriptions, require light sources of relatively

* A paper read at a meeting of the New England Section of the Illuminating Engineering Society, November 10, 1914.

large dimensions, as they tend to reduce intrinsic brilliancy and glare and improve diffusion. But the effectiveness of an illuminant when used with parabolic reflectors or lenses depends greatly upon its concentration into small dimensions. In fact, the nearer the illuminant approaches zero dimensions the nearer do the resultant effects approximate the sharply outlined beams so important in light projection.

Undoubtedly these conditions are better met by the crater of the carbon arc than by any other form of illuminant, for high power work, but the purpose of this paper is to call attention to the demand for apparatus using a lower power concentrated light source, which does not require expert adjustment, trimming and other minor attention.

After testing different lenses, reflector lens combinations and reflectors, I have come to the conclusion that for a general commercial proposition, combining effectiveness of beam, low initial cost, maintenance, etc., the polished parabolic reflector of metal or silvered glass has many points of superiority.

A parabolic reflector is, of course, understood to be a concave reflector having a specular surface, so designed that all sections through the axis of the reflector are parabolas of identical focal length. Such a reflector has the unique property of reflecting all rays of light, emitted from the exact focal point and impinging on its surface, along lines parallel to its axis. Since it is impossible to obtain mechanically a perfect parabolic reflector and since no true point source of light is available, the ideal parallel beam is never realized. Thus, granting that all sources of light have more or less definite dimensions, a distinct angular dispersion is caused. A ray of light proceeding from the light source at the true focal point and impinging upon the reflector will be reflected in a direction parallel with the axis. Another ray proceeding from a point in the light source forward of the focus will be converged across the axis, while a ray emanating from a point back of the focus will diverge. So it may be said that dispersed cones of light will be emitted from all points on the reflector surface, each cone having an angle equivalent to that which the source subtends with reference to the particular points.

It follows, therefore, that the angle of dispersion will increase

with increased dimensions of the light source and decrease with increased distance of the light source from the reflector, or in other words, with increased focal length.[1] Considering the reflector from the light source a distance sufficiently great that it becomes essentially a point, all the light cones may be considered to merge into a single cone and the relation which exists for one cone holds approximately for all. So in considering the effect of a projector at a distance of two or three hundred times its diameter, it can be said:

First, with a light source of given dimensions, everything else being equal, a reflector having the greater focal length will give the greater concentration of beam.

Second, for a reflector of a given focal length, the angle of dispersion of reflected light will be approximately proportional to the dimensions of the light source.

As the focal length is increased, the parabolic curve opens out very rapidly so that in cases where the diameter is limited, a reflector of long focal length will cover a smaller solid angle about the light source. The focus-type lamp gives approximately the same intensity in all directions, so that the light flux striking the reflector, which avails in producing the beam is nearly proportional to the solid angle covered by the reflector. Therefore, for a given diameter of reflector, the shorter the focus the greater the amount of light flux impinging upon the reflector and redirected to the beam.

In the practical design of a projector, the reflector and lamp are of first importance. The diameter of the reflector is usually limited by the cost and the possibility of mechanically accurate work, as well as by the space at the disposal of the user. For example, in the case of application to the automobile, it is necessary for the designer to consider proportion as well as efficiency; so that the diameter of the reflector, as well as the size of the incandescent lamp, is limited. Thus a short-focus reflector is essential in producing the most efficient beam, since it covers the greater solid angle about the light source.

Electric railway requirements may be divided into three classes: city, suburban and interurban. The first requires in most cases

[1] G. H. Stickney, *General Electric Review*, Dec., 1912. F. Nerz, Searchlights; Their theory and Application, Franklin, Electric Lighting.

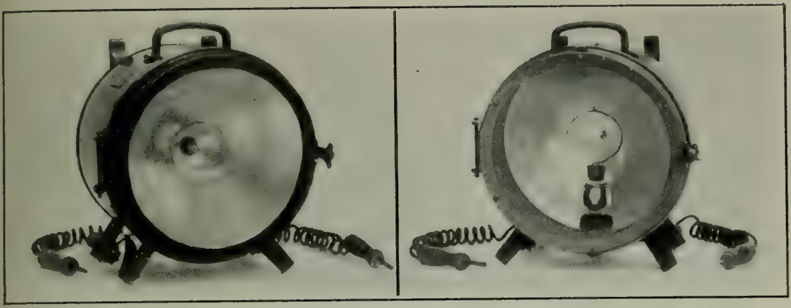
simply a marker on the front end of the car, as the streets are usually well illuminated from other sources. The second requires sufficient illumination to enable the motorman to discern objects on dimly lighted streets of the outlying districts. In the third case powerful projected beams are necessary, since there is often no light on the right of way and the speed of the cars is accelerated in many cases to sixty miles an hour, or over, and it is imperative, therefore, that the motorman discern an object at a sufficient distance to allow him to bring his car to a stop that he may avoid striking it.

It is at present customary in practically all suburban and interurban work to use a portable headlight, which may be carried from one end of the car to the other. Thus, the size and weight of the head lamp must be kept within reasonable limits.

Fig. 1 shows a type of incandescent headlight for suburban or moderate speed interurban cars. Fig. 2 is a headlight for interurban cars.

A word on the development of the spun parabola may be of interest to those who are not familiar with the process. First, a wooden or steel form is turned out on a lathe so that the outside surface conforms to the drawing of the inside surface of the parabola which is about to be produced. Then a piece of circular metal stock, of sufficient area to cover the form, is selected and held centrally between the form and a disk chuck on a lathe. The spinner then proceeds to cause the circular blank and form to rotate and by the use of blunt nose spinning tools proceeds to force and stretch the metal over the form. The piece is then trimmed at the edge, skimmed inside and then sent to the finishing room for plating and buffing. Metal parabolas may be produced with dies, but the larger sizes are more successfully spun.

Glass parabolas are often pressed, while in a hot pliable condition, into moulds and then accurately ground, polished and silvered. Such reflectors are naturally truer than spun metal ones. Other glass parabolas are blown into moulds and prove sufficiently accurate for all practical purposes. The pressed, ground and polished parabolas are naturally very expensive and



Figs. 1 and 2.—Two types of incandescent headlights.

Fig. 3 (on left)—Locomotive headlight; Fig. 4.—Dasher type headlight.

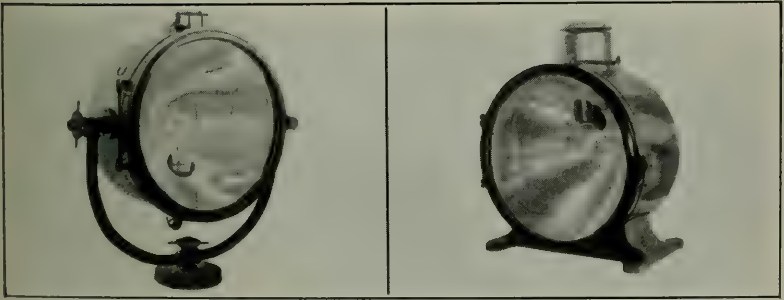


Fig. 5 (on left)—Incandescent projector; Fig. 6.—Locomotive headlight.

Fig. 7.—A locomotive headlight in place.

Fig. 8.—A special rear-end equipment.

their cost precludes their universal use in the larger sizes for railways.

The shallow parabola 11 in. (27.9 cm.) in diameter, 4 in. (10.1 cm.) focus, in the suburban headlight referred to above, was designed to permit the use of lamps having bulbs as large as 5 in. (12.7 cm.) in diameter operating between 80 and 125 volts, with wattages of from 100 to 320. The filaments of these lamps do not reach the degree of concentration of the low voltage high current lamps. Thus the shallow parabola aids in preventing too great dispersion, as well as permitting the use of the large sized bulb.

The deeper parabolas 12 in. (30.48 cm.) diameter, 1⅜ in. (3.49 cm.) focus, with which the suburban headlights are equipped, permit the efficient use of the more concentrated filament focus-type lamps, operating at 6 volts and 105-125 volts at wattages of 36, 72 and 108, and 23, 36, 46, 56, 72 and 94, respectively, having bulbs as large as 2⅛ in. (5.39 cm.) in diameter. The silvered glass parabola is the more efficient as it has the truer reflecting surface.

The rough usage to which this class of apparatus is subjected, makes it imperative that the lamps and reflectors be encased as strongly as possible. Struck-up steel cylinders are used, which are formed from deep drawing steel in a die. There are no seams, as this method provides a one-piece casing which is extremely rigid. The doors which contain the glass fronts are also struck-up and punched hinges are used. The hanger straps and supporting legs are punched and riveted to the casing.

Another and more powerful headlight (Fig. 3) having a rolled steel casing supported on a cast iron base, with classification number boxes is available. This has been designed for use on electric locomotives but can be applied as well to steam locomotives. Here a larger reflector (20 in. (50.8 cm.) diameter, 2¾ in. (6.98 cm.) focus) has been designed. It can be furnished in either brass or copper, silver plated and buffed or in buffed aluminum. Copper is generally used for steam road service as the metal resists the action of the gases so prevalent about large stations and roundhouses. It is easier to spin than brass, but does not usually take on so good a finish as brass, as the metal in

sheet form seems of somewhat coarser grain. Aluminum retains its polished surface, as a rule, a little longer than silver and is to be preferred in some instances, although the coefficient of reflection for silver plate is approximately 86 per cent. against approximately 61 per cent for sheet aluminum.

It is quite important that electric and steam locomotives employed in hauling passenger and freight trains be equipped with classification numbers as a means of identification for tower and switch men. This has been taken care of by the employment of number boxes riveted to the sides of the casing. Each box is provided with an opal glass diffusing member and a hinged door containing a stencil and clear glass. Both glasses are puttied into their frames to keep out the water and the doors are made water-tight where they fit the number boxes, being held tightly by latches and wing nuts. Light from the incandescent lamp is permitted to pass through slits in the reflector and is diffused by the opal glass sharply defining the numbers cut in the black stencil.

There is a growing demand for a headlight for city and suburban use which will project a beam comparable with that of the more powerful automobile headlights, as the usual dasher type headlights are in many cases insufficient. Such a headlight (Fig. 4) has been developed and apparently meets the conditions very nicely. It has so far been constructed with a cast iron casing, but it can as well be furnished in cast aluminum. A circumferential flange for attachment to the car dasher projects midway between front and back, so that the device can be set into the dasher. The casing contains a deep glass parabolic mirror approximately 8⅜ in. (21.27 cm.) in diameter and a reliable focusing mechanism, which, by the way, is somewhat conspicuous by its absence in similar types on the market to-day. Tests on this device have proven quite satisfactory. It could be easily converted for automobile service by a redesign of the casing.

Too much cannot be said about the necessity of accurately focusing the lamps. A slight variation from the proper focal point oftentimes causes an amazing reduction in apparent beam candlepower. The better forms of focusing devices permit of

adjustment backward and forward along the axis of the reflector, as well as radially.

In such cases as the wattage of the lamps employed will permit, it is desirable to exclude all free air from headlight casings, as this prolongs the life of the surface of metal reflectors. This is accomplished by means of felt gaskets applied between the door and casing. In cases where the wattage of lamps is so high as to reduce their normal rated life where enclosed, there is no alternative but to ventilate them well.

Another problem is the use of suitable glass in the doors. The glass must be of good quality, low absorption and, when high wattage lamps are used, must be composed of two layers of sectional glass, one section staggered with respect to the other, to reduce the effects of unequal expansion and contraction, or of a special single pane of very refractory glass to answer the conditions. Oftentimes birds, blinded and dazed by the glare of the headlight, have come to grief within the confines of the reflector when the door glass perchance was not sufficiently strong to withstand the impact.

Fig. 5 shows a simple form of incandescent projector with swivel and trunnion base. This device is equipped with a 20 in. (50.8 cm.) silvered metal parabola with 2¾ in. (6.98 cm.) focus and a special 1,500 mean horizontal candlepower focus-type tungsten filament, which operates at approximately 30 volts, in series with a variable resistance on 110-volt direct current. It will operate as well from a transformer or compensator from an alternating current cicuit.

In general, I might say that for the highest speed interurban direct current service the tungsten filament lamp so far has its limitations and the present luminous arc head-lamp will without doubt be used for this purpose for some time to come. The reason for this is that in order to reduce the dimensions of the tungsten filament sufficiently to put it on a competitive basis with the arc, it is necessary to operate it at very low voltage and comparatively high current, so that operating from a 550-volt circuit the total wattage becomes a prohibitive factor. Where alternating current circuits are available a compensator may be introduced so that in this case no obstacle presents itself. The same

is true with respect to storage batteries. Also on existing 25-cycle alternating circuits, the incandescent headlight is a boon as the fluctuations of any appreciable extent are not observable, while in the electric arc they are plainly visible.

If it were possible to obtain the ideal case of parallel rays, candlepower could not apply on account of the failure of the inverse square law. But, practically, at distances where the beam can be considered as a single cone of light it is apparent that the section of the beam will vary proportionally in area with the square of the distance from the reflector. This being granted and ignoring the absorption of the atmosphere, intensities at various distances will be inversely proportional to the square of the distances. Thus, in working at long range, there appears to be no reason why the intensity cannot be referred to as apparent beam candlepower, since this defines it as compared with the candlepower of the original light source, if the distance at which the test is made is given.

Apparent beam candlepowers obtained with parabolic reflectors are enormous as compared with the original light sources without reflectors. The reason for this is that a large part of the flux of light, instead of being radiated in all directions is condensed into a relatively small angle and thus reaches a much higher intensity. The ratio between the apparent beam candlepower and the mean spherical candlepower of the light source is often referred to as the multiplying factor. This depends upon the diameter and focal length of the reflector, the dimensions of the light source and the percentage reflection of the surface.

The multiplying factor of the 20 in. (50.8 cm.) diameter silvered metal reflector with 2¾ in. (6.98 cm.) focus equipped with a special 6-volt, 126.3-cp. concentric helix filament tungsten lamp has been proven by actual test[2] to be approximately 5,500.

Much discussion has arisen concerning what constitutes a proper apparent beam candlepower for steam railroad service. Certain states have statutes requiring 1,500 unreflected candlepower. The special 1,500-candlepower focus-type tungsten lamp previously referred to, when placed at the focal point of the 20 in. diameter parabola shown, will give an apparent beam

[2] Test by L. C. Porter, Harrison, N. J.

candlepower of approximately 1,100,000. Other states require that an object the size of a man, in dark clothes be observed at a distance of 800 ft. in front of the locomotive on a dark night.

The Report of the Committee on Locomotive Headlights issued by the American Railway Master Mechanics Association calls for a headlight having a maximum beam candlepower not greater than 3,000, referred to the center of a reference plane, from 500 to 1,000 ft. (15.24 to 30.48 km.) ahead of the locomotive

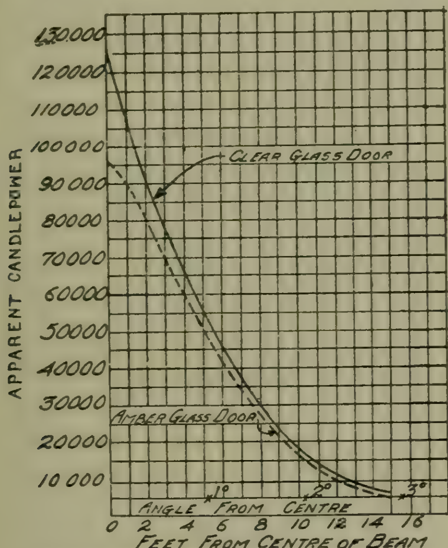


Fig. 9.—Curves obtained from a headlight equipped with a 6-volt, 36-watt focus-type tungsten headlight lamp.

and not greater than 2,800 at the same distances in front of the locomotive, but taken at 20 ft. (6.09 m.) either side of the axis. (Height of the headlight 9 ft. 7 in. (2.92 m.) above the rail.) The 20 in. (50.8 cm.) diameter reflector previously referred to in this article will accomplish these results when equipped with a suitable tungsten lamp.

In due time it is to be hoped that a national law will be made to regulate the intensities of headlight beams. Such a step will serve towards a considerably greater uniformity in design than is now possible.

Fig. 9 shows curves obtained from a headlight (Fig. 2)

equipped with 6-volt, 36-watt focus-type tungsten headlight lamp. The full line curve was taken with a clear glass door pane. The dotted line curve was taken with an amber glass door pane. Observation tests made at Lynn show no apparent reduction in glare at the same measured apparent beam candlepower for the amber glass screen over the clear.

Fig. 7 shows a Boston & Maine locomotive equipped with turbo-generator headlight outfit. Capacity of set is 100 watts and generator delivers 6 volts, 9 amperes to the lamp. The headlight is here shown mounted on the smoke-box door of the locomotive, while the turbine and generator are located on top of the engine just ahead of the cab roof.

Fig. 8 shows an incandescent headlight applied to gasoline electric cars. Approximately seventy-five of these headlights are in service, using 35-volt, 110-watt focus-type tungsten lamps operated in series with a resistance from a 65-volt direct current car lighting generator and are giving very satisfactory service.

Thus it may be observed that considerable attention has been given to the design, construction and operation of incandescent headlights and projectors for practically all service requirements.

STREET LIGHTING IN CHICAGO.*

BY PIERRE E. HAYNES.

Synopsis: This paper describes a few of the most interesting engineering problems met with during the rehabilitation of the street lighting system of the City of Chicago. The method of arc lamp selection is suggested as a method of approximation which is generally acceptable to arc lamp manufacturers, and still enables the purchaser to obtain the very best value for his money. The subway illumination design is a distinct refinement in outdoor lighting where comparatively high intensities are desired on both horizontal and vertical surfaces with a minimum of glare.

The first attempt to illuminate the public streets of Chicago was made in the year 1805. At that time the hunters and trappers following an old pathway along what is now Archer Avenue extended their operations down as far as 18th or 22nd Streets. The trip was at that time quite difficult and in order to guide the hunters back to the fort a pine knot was fastened to a tall pole and lighted every night. This improvised lamp was set up probably a little east of the south end of the present Rush Street bridge.

Little or no attempt at street lighting was made until the manufacture of coal gas was started in the year 1850. The council proceedings subsequent to that time contain many orders for the setting and operation of flat flame gas lamps. Many lamps of this type remained in service up to two or three years ago.

In the year 1887, 105 electric arc lamps were installed east of the Chicago River from Kinzie to Polk Streets and since that time the total number of such units in service has increased while the number of gas lamps decreased.

The adequate illumination of the streets of Chicago requires the use of electric arc lamps, tungsten incandescent lamps, ordinary and ornamental gas lamps and incandescent gasoline lamps.

The use of electric arc lamps is confined as nearly as possible to business streets, traffic streets, and unshaded residence dis-

* A paper read at a meeting of the Chicago Section of the Illuminating Engineering Society, June 10, 1914.

tricts or in districts where the density of population is not sufficiently high to warrant the high initial cost of ornamental tungsten lamp post construction. The total number of arc lamps in service is about 19,000, of which 11,444 are 10-ampere alternating current flame arc lamps. The remainder of the lamps in service consist of direct current open and alternating current enclosed arc lamps, there being about 1,000 of the former and 6,000 of the latter.

The keen quality competition of the American arc lamp manufacturers and the price competition of the foreign manufacturers necessitated more exact methods of comparison than has heretofore been used in the selection of such units. The American manufacturers took ready advantage of many of the suggestions made by the city's engineers and as a consequence changed some points in their lamp design very materially.

SELECTION OF ARC LAMPS.

The proper selection of an arc lamp must take cognizance of many points and in order that a proper grading may be given to each type of lamp submitted, each of these points must be given a weighting so that the grading given to each type will fairly represent the value of that unit under the conditions for which it is selected. Out of a total of 168 points allowed for a perfect lamp, the various characteristics were graded as follows:

Total light flux	10
Light distribution	10
Light constancy	10
Light efficiency	10
Mechanical efficiency	5
Regulation of voltage	5
Power factor	3
Accessibility of mechanism	20
Design	20
Materials	20
Reliability	30
Carbon consumption	25

Attention will be directed to the methods used in estimating only two of the points listed above, the other methods being obvious from the name assigned to the different characteristics.

In a large shop the matter of standardizing stocks of materials, spare parts, and shop routine becomes extremely important if any

efficiency is to be obtained, and an attempt was made in this case to reduce the number of parts in a lamp to a minimum, to make these parts accessible as they are assembled in the lamp, and to reduce the number of special parts as far as was practicable. In order to determine which of the competing lamps was best according to this standard, accessibility or dissembly tests were made. The various lamps submitted were taken to the city shop and placed in the hands of any operator which the manufacturer desired to furnish. This operator was required to dissemble and assemble some eighteen or twenty parts characteristic to all lamps competing. The number of smallest parts handled and the number of operations were recorded and the total for each lamp taken inversely represented to a fair degree the relative value of the lamp to its competitors. In every case the lamp showing the best grade was given the maximum value shown on the table previously given. It was interesting to note that three distinctly different types of lamps did not vary more than 25 per cent. from each other in accessibility by this method of test while the various estimates based purely upon the judgment of experienced men varied as much as 100 per cent.

In the matter of design, the grades were assigned after a very careful consideration of the fundamental principles involved and the manner and extent in which the manufacturer had adhered to them. Attention is called to the fact that some serious departures from a theoretically perfect lamp were found.

The posts (Fig. 3) used for mounting flame arc lamps have been approved by the Chicago Art Commission and are standard in this city for this type of construction.

LIGHTING OF SUBWAYS.

In Chicago the steam railroads are elevated and at intersections of these elevations with public streets there are found what are termed "subways." These subways or viaducts were a source of considerable danger on account of lack of illumination until a short time ago. Where the elevation ordinances specifically require it, the railroads have or are planning to illuminate these subways according to specifications drawn by the commissioner of gas and electricity. The remainder are now lighted by the

city according to specifications considerably better than those under which the railroads are required to work.

The railroads first proposed a method of installation of subway illumination and one subway was wired according to this method. Fig. 1 shows this subway at night time under the illumination provided by the railroad method. The shadows and glare spots are quite noticeable. The department of gas and electricity then made an installation according to what seemed to be the best and most practicable method. Fig. 2 shows the result. Here it is plain that practically all shadows have been eliminated. Subsequent tests showed that the illumination derived from the railroad method was inadequate. The city method provides more uniform illumination in the line of most rapid travel, the vertical surfaces are adequately illuminated, and the angle reflectors shade the eyes from the intense glare of the lamps in the driveway.

Following the subway illumination work attention was turned to grade crossing illumination. Fig. 7 shows a sheet used in the department of gas and electricity by foremen in laying out subway and grade crossing jobs. Over 4,000 25-watt tungsten lamps are in use in the subways lighted by the city. Each lamp serves approximately 400 sq. ft. (36.8 sq. m.) of subway area. All lamps are installed in high grade porcelain steel reflectors. Driveway lamps are installed in angle reflectors and are placed over the curb and the horizontal axis of illumination turned 45 deg. toward the direction of traffic.

INCANDESCENT LAMP LIGHTING.

Electric.—The construction of the ornamental tungsten lamp post lighting system (Fig. 4) made use of old gas lamp posts. This installation consists of the old post with a top casting which supports the globe and contains a series lamp socket with a film cut out. The illumination obtained from this unit is of very low intensity, quite uniform, and extremely pleasing. Moreover, visual efficiency under the illumination provided is very high considering the low foot-candle values found.

Gasoline.—The gasoline lamp has been used for many years for the illumination of isolated locations where gas or electricity are not available.

Fig. 1.—Railroad subway lighting.

Fig. 2.—Railroad subway lighting.

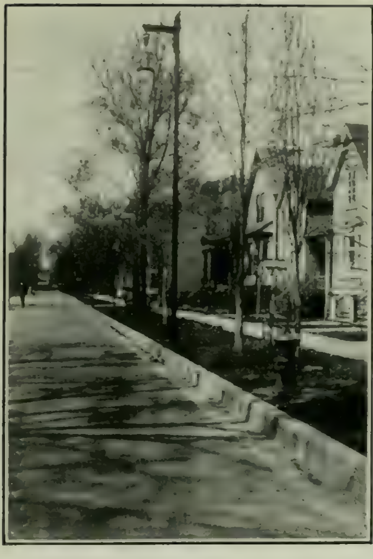


Fig. 3.—Flame arc lamp and standard post.

Fig. 4.—Electric incandescent lamp post with street sign attached.

Fig. 5.—Ornamental gas lighting standard.

Fig. 6.—Standard post for commercial lighting.

The amount of gasoline consumed is 65 grams per hour per lamp and the candlepower obtained is in excess of 50 at the horizontal.

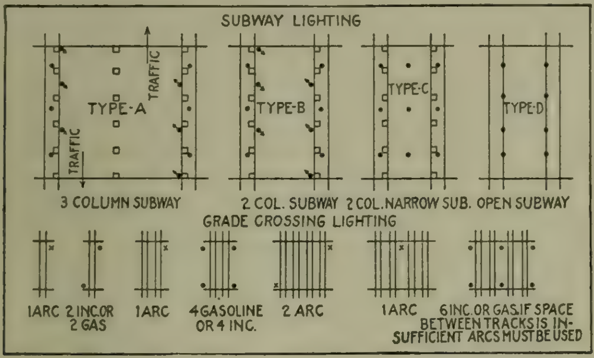


Fig. 7.—Plan used in laying out subway lighting.

Gas.—Up until a very few years ago the city used an old type of incandescent gas lamp which was capable of giving from 25 to 30 cp. on the average. This unit now yields in excess of 50 cp. measured horizontally and uses less fuel than before.

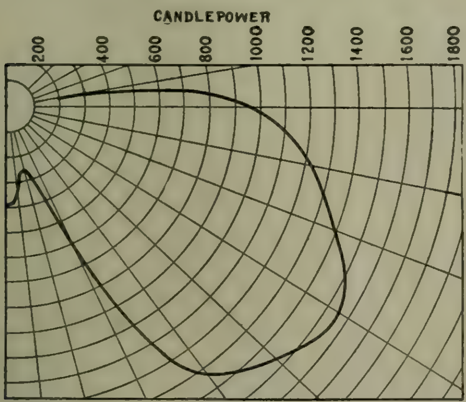


Fig. 8.—Light distribution from 10-amp. alternating current flame arc lamp shown in Fig. 1.

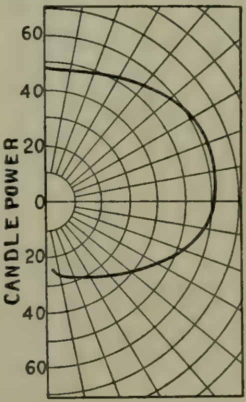


Fig. 9.—Light distribution from tungsten lamp unit shown in Fig. 2.

The increase in efficiency of street lighting in this city has been remarkable during the last three years. Both the number and efficiency of units have been increased while costs with the exception of the cost of gasoline units have decreased. The cost of operation of gasoline units has increased on account of the

change in market price of the fuel used. This cost is now so high that the gasoline lamp is being replaced as rapidly as possible by other and cheaper types.

The method used in checking the candlepower and continuity of service of gas and gasoline lamps is worthy of mention. Twenty-five per cent. of all gas and gasoline lamps in each class of service are inspected each month during the lighted period. The condition of all lamps inspected is considered as indicative of the condition of all lamps of that class of service for the whole month and a deduction is made from the contractor's bill based on whatever percentage of lamps tested or inspected fall within the limits of the following classes:

Candlepower		
45	Excellent	No reduction
35–45	Good	5% "
25–35	Fair	20% "
15–25	Bad	80% "
	Out	100% "

Photometric measurements are made from time to time, measurements being taken of horizontal candlepower with all glassware in place These tests are made on the street using a portable photometer in connection with a special adjustable stand which is carried on a wagon. All tests are taken directly from the wagon and it is unnecessary to climb out except to measure the distance from the lamp to the photometer screen.

ORNAMENTAL LAMP POSTS.

A demand has arisen for an ornamental gas lamp. The use of the present type of lamp with diffusing glass did not appear to be the best thing obtainable. Single and upright mantle lamps were tried in spherical globes and finally a vase shaped globe was tried. The effect, using this globe, was very satisfactory, the internal reflection of the globe making the single inverted unit as efficient with diffusing glassware as it was in the old type of lantern with clear glassware. Exhaustive tests of this type of globe (Fig. 5) showed that it increased the amount of downward illumination with all mantle combinations, but that the maximum increase of 23 per cent. was obtained using the single inverted mantle. This unit will be used wherever it is desirable to have an ornamental gas unit.

Various special problems come up from time to time and these are handled with the general idea that fixtures and operative methods are to be standard and that intensity must be uniform and brilliancy low.

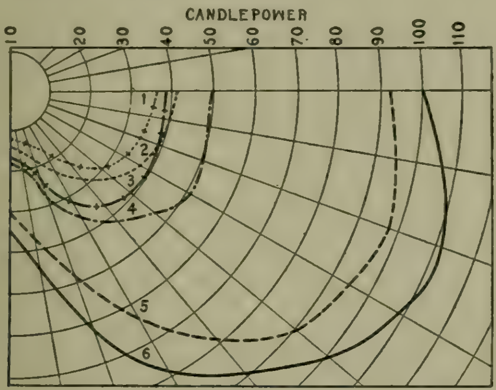


Fig. 10.—Light distribution from (1) single upright mantle with round white glass globe; (2) single upright mantle with vase shaped white glass globe; (3) single inverted mantle with round white glass globe; (4) single inverted mantle with vase shaped white glass globe; (5) double inverted mantle with round white glass globe; (6) double inverted mantle with vase shaped white glass globe.

The development of the new commercial lighting post (Fig. 4) used principally by the Commonwealth Edison Company followed out these ideas very strictly. The post itself was designed by the Art Commission and the choice of lamps, lamp heights, and glassware was prescribed by the city.

In the business districts this post must be 16 ft. (4.87 m.) from the street level to the center of the suspended globes and in outlying districts this dimension must be 12 ft. (3.65 m.). The increase in efficiency was remarkable when the old height of 10 ft. (3.04 m.) was compared with the newer heights of 12 and 16 ft. All the new cluster lighting upon Chicago streets must be of this type (Fig. 6) at the end of five years.

DISCUSSION.

Mr. Hans Schaedlich: The lighting system of Chicago is different from that of any other city in the world in that the series circuits are fed in multiple from 250 kv-a. transformers.

These transformers supply current for from six to fifteen circuits at a potential of 5,050 volts. In order that a ground upon one circuit may not react upon the operation of the other circuits operating from the same transformer, one side of the transformer must be grounded permanently. The transformers are connected in banks of three, delta on the primary and star on the secondary side, with the neutral grounded. This system of operation has two special features, one is that the occurrence of a ground causes a short circuit upon the line and the other is that on underground circuits there is a considerable difference of current between the phase and neutral ends of the circuit. The first of these peculiarities is taken care of by the careful selection of the current regulating device, and the second by the proper balancing of the capacity and reactance of the lines.

The question of the gas-filled tungsten lamp standing up under the shocks of operation due to grounds was satisfactorily settled by repeatedly subjecting two of these units to the worst condition possible. For this test the lamps were placed upon an experimental circuit fully loaded and all the load with the exception of these two lamps was suddenly short-circuited through an oil switch. This test was repeated some twenty times and the lamps withstood this treatment perfectly. The lamps are now burning upon arc circuits. This test subjected the lamps to more excess rushes of current than would occur during several years of actual operation.

The size of the unit selected is the 300-watt 600-candlepower 20-ampere lamp. The lamp housing was designed by the city's engineers, as the appearance of the units on the market were so radically different from that of the flame arc units now in service as to hamper the uniformity of the lighting system. Furthermore, the ventilation of the fixtures on the market was not sufficient, in the opinion of the city's engineers, to properly dissipate the heat generated by the lamp.

The 600-candlepower lamp is, due to the steadiness of its light and due to lack of depreciation of the volume of light (as during a trim of an arc lamp) at periodic intervals, slightly superior to the flaming arc lamp with its initial maximum candlepower of 1,150 through a diffusing outer globe.

TRANSACTIONS
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THE THEORY OF COLD LIGHT.*

BY WILDER D. BANCROFT.

Professor of Physical Chemistry, Cornell University.

Synopsis: It is claimed that all chemical reactions tend to emit light and that they all emit light if made to take place very rapidly. It is shown that the luminescence of salt flames is a chemiluminescence, and the method of determining the reaction is outlined for the specific case of cupric chloride. If a suitable chemical reaction can be made to take place sufficiently rapidly, without any marked evolution of heat, cold light is obtained. The firefly has solved this problem, though the nature of the substance which oxidizes is not known. The chemist will some day solve it in another way. The Moore light is probably a case of chemiluminescence; but most commercial forms of lighting depend on temperature radiation for their efficiency.

When opaque substances such as carbon, platinum or earthenware are heated sufficiently they emit light, the quality and intensity of which depends on the temperature and not on the nature of the substance heated. Radiation of this sort is called temperature radiation. An opaque gas would also emit light if heated to a suitable temperature. Iodine vapor, for instance, glows[1] when heated to above 500° C. While this may not be entirely a temperature radiation, it is usually so considered. The law of temperature radiation holds only for opaque substances, which are sometimes called perfect radiators. An absolutely transparent substance would give no temperature radiation. At the end of the eighteenth century Wedgwood[2] showed that heated air is not luminous. Subsequent experiments have confirmed this conclusion of Wedgwood's.

Most artificial lighting is due to temperature radiation from

* A paper read at a meeting of the Pittsburgh Academy of Sciences and the Illuminating Engineering Society, December 10, 1914.

[1] Salet; *Ann. Chim. Phys.* (9) vol. 28, p. 34; 1873. Cf. Bancroft and Weiser; *Jour. Phys. Chem.*, vol. 18, p. 295; 1914.

[2] *Phil. Trans.*, vol. 82, p. 272; 1892. Cf. Bancroft and Weiser; *Jour. Phys. Chem.*, vol. 18, p. 281; 1914.

solid particles. In the kerosene lamp the light is due to glowing particles of carbon. The difference between the kerosene lamp and the gas jet is that the temperature of the latter is higher. If all the solid particles are burned, as in the Bunsen burner, a so-called non-luminous flame is obtained, even though the temperature is much higher than in the burner with a luminous flame. The brilliancy of the lime light is due to temperature radiation from intensely heated lime. In the Welsbach mantle and in the Nernst lamp there are suitable mixtures of rare earth oxides instead of the calcium oxide used in the lime light. There is some question whether the light from the Welsbach mantle is exclusively due to temperature radiation, but it is unnecessary to go into that matter now.

At first one would suppose that the incandescent lamp would give the most efficient temperature radiation known because graphite melts at a higher temperature than any other known substance. The carbon lamp can be made to give an extraordinary light efficiency, but its life is extremely short under these conditions. The graphite vaporizes or disintegrates and the filament breaks.[3] There has therefore been a systematic search for substances with high melting points and low vapor pressures. As a result, there have been produced successively the osmium, the tantalum, and the tungsten lamps. In the nitrogen-filled tungsten lamp the thermal radiation has been cut down and consequently less power is needed to heat the filament to a given temperature.

While it would be foolish to claim that the limit of efficiency has been reached, it must be remembered that a large number of very able men have been attacking this problem of temperature radiation systematically and that consequently the limit of efficiency is probably being approached. That brings up the question whether light may not be produced in other ways than by temperature radiation and, if so, whether it is possible to produce cold light. The possibility of cold light cannot be disputed because the firefly produces it. Langley's studies of the firefly have shown that the insect gives about 95 per cent. efficiency, meaning thereby that 95 per cent. of the radiations are in the

[3] Werner von Bolton obtained 0.3-watt per candlepower for a moment with a tantalum lamp.

portion of the spectrum visible to the human eye while only about 5 per cent. of the radiations are in the ultra-red portion of the spectrum and what are popularly called heat rays. The light of the firefly cannot be due to a temperature radiation because the firefly does not burn up instantaneously. It is not a question involving life because the abdominal portion of the firefly can be dried, pulverized in a mortar, and kept for two years. At the end of that time the powder will glow if moistened and exposed to oxygen. It is simply an oxidation process. The firefly has the power of secreting a substance which burns with a luminous, cold flame. If one were to make in the laboratory the unknown substance which the firefly makes, it would behave in exactly the same way as the natural product. It would be amusing to do this; but that is all that it would be, because the product would be too expensive to use as a source of light. Nobody claims for the firefly a low cost of production. In fact, it is not known how one would estimate the firefly's cost of production.

Under certain circumstances cold light can be produced in the laboratory. Angström[4] has calculated that he gets about 95 per cent. light efficiency when he passes a current through nitrogen under 0.1 mm. pressure. The losses at the electrodes and at the walls of the tube cut the working efficiency down to about 8 per cent. From this work of Angström's, it seems probable that the Moore light is not a temperature radiation but is due to chemical reactions.

Phosphorescing substances, such as zinc sulphide, emit light at low temperatures and do not involve temperature radiations. As yet, however, such substances as Balmain's paint, etc., have to be exposed to light before they will emit light. Until some other way of stimulating them is found, they are of more theoretical than practical importance. At present very little is known about the chemical reactions involved, because these substances have been studied chiefly by physicists.

The luminescence of salt flames are of great importance theoretically. By putting different salts into the non-luminous flame of a Bunsen burner different colored flames are obtained: yellow

[4] *Wied. Ann.*, vol. 48, p. 493; 1893.

with sodium, pink with lithium or strontium, blue or green with copper. Since the temperature of the flame is about the same in all these cases and since one cannot very well claim selective absorption in each case, it seems certain that the colors of these flames are not due to temperature radiation and the problem is to find out what does produce the luminescence.

One usually gets the same yellow color with different sodium salts and one is consequently tempted to say that the yellow color is due to the sodium atom when heated to a suitable temperature. This is not true, however, because sodium salts emit little or no yellow light in the hydrogen-chlorine flame, even though this is fully as hot as the flame of the Bunsen burner.[5] The next assumption is that the yellow color is due in some way to sodium metal and that the metal is present in one flame and not in the other. The presence of free metal in the flame is not impossible. Almost all salts are formed with evolution of heat and consequently will dissociate if the temperature is high enough. It therefore becomes a question of fact whether a given salt dissociates in a given flame or not. To test this, use has been made of a modification of Deville's hot-cold tube. Cold water was run through a porcelain tube and the chilled porcelain tube was held in the colored flame. With salts of copper, cadmium, tin, silver, lead, bismuth, zinc, antimony, and arsenic in the Bunsen flame, mirrors of the metals were obtained on the porcelain tube.[6] With salts of mercury a grey deposit was obtained consisting of drops of mercury. No experiments were made with gold or with the platinum metals. No mirrors of tungsten or molybdenum could be obtained from oxides of these metals in the Bunsen flame, but good mirrors were obtained with the hotter oxyhydrogen flame. From the cooler portions of the oxyhydrogen flame tungsten blue and molybdenum blue were precipitated on the tube. When sulphur dioxide was led into the hydrogen-air flame, sulphur was precipitated on the porcelain tube. No copper was obtained when copper salts were fed into the hydrogen-chlorine flame, showing that the amount of metallic copper present in this flame is at any rate very much less than in the Bunsen flame.

[5] Cf. Bancroft and Weiser; *Jour. Phys. Chem.*, vol. 19, p. 310; 1915.

[6] Bancroft and Weiser; *Jour. Phys. Chem.*, vol. 18, p. 261; 1914.

It is not to be expected that mirrors of metallic sodium and potassium would be produced. There is, however, some evidence that the metals are actually precipitated. The sodium chloride is distinctly alkaline when precipitated from the hottest flames. This is probably not due to hydrolysis in the heated gases, because caustic soda is more volatile than sodium chloride and consequently should be found in larger amounts in the outermost portions of the flame. This is not the case, for the sodium chloride from the outside of the flame is neutral. The greatest alkalinity is obtained under the conditions under which one should expect to have the largest amount of free metal. While this is not absolutely conclusive in itself, it is pretty satisfactory when taken in connection with the behavior of the other metals.

It is evident that a number of reactions are taking place simultaneously in a flame colored with a salt. It is now believed that all reactions tend to emit light[7] and that they all emit light if made to take place very rapidly, the critical reaction velocity varying enormously in different cases. It is known that increasing the rapidity of a reaction which emits light increases the intensity of the light[8] without producing much change in the quality. While the vaporized salts are sometimes colored, as in the case of cupric chloride, and may therefore give temperature radiation to some extent, it is clear that most of the light emitted by salt flames is due to chemical reactions and is to be classified as chemiluminescence.

Some progress has been made in determining the reaction corresponding to a given color. The following results[9] were obtained for copper salts in the Bunsen flame:

I. Cuprous ion to cuprous salt = red.
II. Copper to cuprous ion = green.
III. Cuprous ion to cupric salt = blue.

The first conclusion is based on the action of cathode rays on cuprous iodide, the third on the combustion of cuprous chloride in chlorine, and the second on the combustion of copper in oxygen. A number of experiments were made on the rapid reduction of cupric and cuprous salts with sodium and aluminum as reducing

[7] Bancroft; *Jour. Franklin Inst.*, vol. 175, p. 129; 1913.

[8] Trautz, *Zeit. Elektrochemie*, vol. 10, p. 595; 1904. *Zeit. Phys. Chem.*, vol. 53, p. 108; 1905.

[9] Bancroft and Weiser; *Jour. Phys. Chem.*, vol. 18, p. 323; *Trans. Am. Electrochem. Soc.*, vol. 25, p. 123; 1914.

agents. No characteristic luminescence could be obtained, presumably because these reverse reactions were not made to go sufficiently rapidly. However that may be, it is clear that reductions play no important part as regards the light emitted by copper salts in the Bunsen flame.

When a solution of cupric chloride in aqueous hydrochloric acid is sprayed into the Bunsen flame, there is a red or violet tip to the flame and when the flame is burning steadily one can often see a violet sheath around the flame. This is not a true luminescence, though it looks like one. It is merely the color of cupric chloride vapor. It can be obtained in mass by heating copper in an electric furnace and then running in chlorine or by volatilizing cupric chloride.

When cupric chloride is sprayed into a hydrogen-chlorine flame or when a mixture of cupric chloride and hydrochloric acid is sprayed into a Bunsen flame, the hydrochloric acid cuts down the dissociation of the cupric chloride and there is a reaction from cuprous ion to cupric salt but not the reaction from copper to cuprous ion. Consequently the flame is blue and not green. The same result ought to be obtained without the acid if one used a flame the temperature of which was not sufficient to dissociate cupric chloride into free metal and chlorine. The alcohol flame is just on the dividing line. Cupric chloride colors a hot alcohol flame green and a cooled alcohol flame blue.

Since the yellow of the sodium flame is due to the reaction from sodium to sodium ion, the hydrochloric acid from a hydrogen-chlorine flame will force back the dissociation and cause the yellow to disappear practically completely.[10]

Since the bulk of the light in salt flames is due to chemical reactions and not to temperature radiation, there is a possibility of duplicating the effect, if one can cause the reactions to take place sufficiently rapidly at low temperatures; in other words, if they are done electrolytically. Some years ago Schluederberg[11] showed, in the Cornell laboratory, that light is emitted when an alternating current is passed through lead electrodes in sulphuric acid. Later, Wilkinson[12] obtained flashes of light with a number

[10] Bancroft and Weiser; *Jour. Phys. Chem.*, vol. 19, p. 310; 1915.

[11] *Jour. Phys. Chem.*, vol. 12, p. 623; 1908.

[12] *Ibid.*, vol. 13, p. 695; 1909.

of metals as anodes, using a direct current. Owing to film formation, the light could only be seen for an instant. By pressing a tooth brush against a rotating anode, it is possible to remove the film as it gets too thick and thus to obtain light continuously for an indefinite period, ten minutes for instance. So far we have not been able to obtain an electrolytic flame with copper which could be shown to a large audience, but we can do this readily with mercury.[13]

When mercurous bromide or mercury is burned in bromine an orange light is emitted. When mercurous or mercuric bromide is exposed to the cathode rays a similar orange light is obtained. When mercury is made anode in a cold, fairly concentrated, potassium bromide solution (25 per cent., for instance) with an anode current density of about 2 amperes per square decimeter, the mercury first becomes coated with a film of bromide and then appears to glow with a brilliant orange light. This will last for at least ten minutes, at the end of which time the film of bromide will have become so thick as to prevent the light being seen. By looking carefully from the side, light can still be seen between the film and the surface of the mercury. The light can be obtained at as low a voltage as 3 volts, but the intensity is then very low. With increasing voltage—or really with increasing current density—the intensity of the light increases, the upper limit coming when visible sparking takes place. The phenomenon is shown very well with a voltage of 24-28 volts.

This is not cold light. It is not even a very efficient light. The importance of it lies in the fact that it is a striking illustration of the principle that reactions emit light and that a high temperature is not essential. To obtain cold light one must find a reaction which can be made to go rapidly, which absorbs heat or evolves but a small amount of heat, and which has a high conversion factor for light. A number of other requirements come in, if it be stipulated that the light shall be suitable for commercial purposes. There is no immediate prospect of the present methods of lighting being superseded; but the theoretical feasibility of cold light and the general conditions under which it is to be obtained have been demonstrated.

[13] Bancroft and Weiser; *Jour. Phys. Chem.*, vol. 18, p. 762; 1914.

PIPING HOUSES FOR GAS LIGHTING.*

BY H. R. STERRETT.

Synopsis: This paper emphasizes the importance of having a specification which will thoroughly cover the installation of all interior gas piping. The method of handling this phase of the distribution system in one city is described. The desirability of illuminating engineers deciding on the location of outlets is also discussed.

Although the Illuminating Engineering Society has primarily to do with the utilization of energy in the form of light, the design of burners and reflectors, the study of the effect of light upon the human eye, the determining of the quality and proper amount of illumination for the great number and variety of conditions under which artificial light is necessarily used, it is the object of this paper to tell something of the means used to convey that form of light energy commonly known as illuminating gas to the various outlets or points where it is to be converted by combustion into light or heat.

Broadly speaking, any distribution system may be divided into four component parts; mains, services, meters and house piping, each of which contributes equally to the satisfactory supply of gas. Of these divisions the first three are under the gas company's control, and hence, are usually properly installed and maintained.

A brief description of a typical low pressure distribution system might now be apropos.

From the works where the gas is made there is a net work of trunk or principal mains, which act as feeders for the thousands of branch pipes which supply gas to all parts of the city. In a large plant gas as manufactured is forced through pusher mains usually of 20 in. or 30 in. pipe (50.8 or 76.2 cm.) pipe,

* A paper read at a meeting of the Philadelphia Section of the Illuminating Engineering Society, March 21, 1915.

under a pressure of from 10 to 70 in. (0.25 to 1.78 m.) water column, the latter being a little less than 3 pounds (1.36 kg.) per square inch (6.45 sq. cm.), to the various holders or reserve tanks.

The pusher mains are so interconnected that, if, for any reason, something unforeseen should happen to either of the manufacturing plants, the other could instantly take up the additional load without endangering the continuity of supply. During the periods of low demand the holders are filled, and when the peak load comes on the gas supply is ample. The gas is discharged from the holder through governing valves into the distribution system, which is under a pressure averaging about 3 inches of water column. The distribution mains, which range from 6 to 48 in. in diameter, are so cross connected and interconnected that any break in the system affects but a few consumers. Continuously recording pressure gauges are set in different parts of the city so that any change in the gas pressure, due to increased or diminished consumption, perhaps caused by a shifting population, can be adjusted by partly closing or opening the holder valve. In this way the general pressure conditions are kept constant within certain limits.

The remaining division of the distribution system, house piping, is usually installed by plumbers or gas fitters, and does not come under the direct control of the gas company. It is, therefore, necessary that this work be properly inspected.

The importance of a specification which will thoroughly cover the installation of all interior gas piping, cannot be too greatly emphasized. In order that such a specification be of any real value, it is very necessary that proper laws be enacted to insure to the gas company the enforcement of the various rules embodied in the specification.

In one large city, before any gas piping may be installed in a building, it is necessary to obtain a permit from the bureau of buildings, which also inspects the work when completed and issues an approval card before a meter may be set. In another city all piping must be installed in accordance with specifications issued by the gas company, whose inspectors supervise the work; while in still another city all gas fitters must be licensed and file a

plan of the proposed piping with the building department for its approval, the gas company supervising the installation.

In one city where about 375,000 meters are in use, the city government by ordinance requires the gas company to exercise a supervision over the character of material used and work done in installing gas piping and fixtures. In accordance with the obligation thus created, the company has adopted a specification for fuel and illuminating piping and fixtures. This specification includes the kind of material, methods, locations, etc., to be used and avoided in making installations, a schedule of pipe sizes and lengths for various consumptions, instruction how to properly draft a piping plan, and an explanation of just what is required in the way of inspections by the gas company's representatives.

The piping schedule is based on Prof. Pole's well known formula for the flow of gas through pipes,

$$Q = C \sqrt{\frac{d^5(P_1 - P_2)}{LW}},$$

where Q = cubic feet per hour; d = diameter pipe in inches; P_1 = initial pressure, inches water; P_2 = terminal pressure, inches water; L = length in yards; W = specific gravity of gas (air = 1); C = constant.

A computer designed by Wm. Cox is based on this formula, and saves much time which otherwise would be spent in making calculations. With the computer, either the discharge, the required size pipe, or the difference in pressure can be determined, provided the other two are known.

If the sizes specified in the schedule are checked with the formula they will be found somewhat in excess of the figures derived from the latter, it being the desire of the gas company to make provision for the future installation of additional appliances without necessitating an increase in the size of piping.

The smallest diameter pipe, and therefore the smallest outlet permitted, is 3/8 in. (9.52 mm.), and this, it is assumed, will usually supply 10 cu. ft. (0.28 cu. m.) per hour at the average pressure. The capacity of a larger outlet as compared with a 3/8-in. outlet, varies directly as the areas. In designing a system of piping, after the sizes of the various outlets and the best direction to run the pipes have been determined, it remains to de-

cide the proper size piping to install. This is accomplished by starting at that part of the system farthest from the meter and working toward the latter, determining the proper sizes by consulting the piping schedule. When the first branch line is reached the sizes are again determined by starting at the far end of the branch and proceeding to the junction, where the quantities of gas for the two pipes are added and the same process repeated until finally the meter is reached.

In drawing a piping plan, vertical lines show vertical piping, horizontal lines show horizontal piping running the length of the building, while the slanting lines show horizontal piping running the width of the building.

When no outlets are open the pressure in a system of house piping is uniform, except the small difference due to elevation, each 10 ft. (2.54 m.) being equal to about $^1/_{10}$ in. (2.5 mm.) water column. Just as soon as a burner is lighted, gas begins to flow through the piping and, as a result of frictional losses, the pressure by the time the gas reaches the burner is reduced. Since it is necessary to have a certain volume of gas at a burner, and since the volume depends on the pressure as well as on the size of piping, a certain pressure loss through a system of piping must be used as a basic, so that in the piping schedule mentioned before a loss of $^2/_{10}$-in. water pressure between the meter and the farth est outlet is considered as maximum. Then since there is from $^{25}/_{10}$- to $^{35}/_{10}$-in. (63.5 to 90. mm.) pressure on the mains and services, the pressure at an appliance connected to the extreme outlet would be from $^{20}/_{10}$ or $^{30}/_{10}$ in., there being about a $^3/_{10}$-in. drop through the meter.

Due to the fact that there is a certain unavoidable range in pressure over an area as great as that included by the limits of a large city, gas appliances are usually equipped with the necessary means of adjusting the burner to take care of the different pressures.

In one large city where the gas company is responsible to the city government for all material and workmanship in the installation of house piping three inspections of interior piping are made, the inspectors being employees of the gas company, impartial and working for the combined interest of the consumer and the com-

pany. When an installation is ready for the first inspection, which is made while the piping is still exposed, a plan of the system or extension, plotted on a regular form, is forwarded to the gas company. The inspector compares the actual installation with the plan, and tests the piping for leaks, a pressure of 3 pounds (1.36 kg.) per square inch (6.45 sq. cm.) as indicated by a 6-in. (15.24 cm.) mercury column, being applied for 10 minutes. If the rules have been complied with, and the system is tight, a certificate of first inspection is issued and the piping may be covered. If any changes are necessary, they must be made before the certificate is granted. After all carpenter and other building work, that might disturb the piping, has been finished, and after the last coat of white plaster is on, the gas fitter applies for the second inspection, which is principally one of pressure and is made before any fixtures are hung. A pressure test identical with that of the first inspection, is made, and if the piping is tight a certificate of second inspection is given. After the fixtures are installed and the system is ready to receive gas, the third inspection is applied for. This, the last inspection, is principally one of fixtures; the entire system is put under a pressure of 6-in. water column, which must show no drop in 10 minutes. Fixtures are examined for poor workmanship, objectionable design, etc., and all gas fixture cocks are carefully measured with a special gauge made for the purpose of determining whether they comply with the fixture cock specification.

There is very little to say about the actual physical house piping. It is simply a case of determining the proper location of, and the approximate consumption of gas for, each outlet, joining the various outlets to the riser, care being exercised so that the piping is of the correct size, properly supported, sloping in the right direction, etc.

In ordinary dwelling houses, which form the great majority of cases, a system of house piping usually consists of a riser or pipe running vertically from a point in the basement near the meter, and supplying gas at each floor to a branch pipe, to which are connected the various outlets on that floor. In larger dwellings two or more risers may be run, all being supplied by one meter; while in the case of apartment houses a separate riser and meter

supplies each apartment. The meters are always installed in the basement, and in some cases where the number warrants, a special meter room is built. In modern manufacturing buildings it is the custom to install a trunk or common riser, the meter or meters being set on each floor, according to the number of tenants occupying it.

In most cases horizontal gas piping is run parallel with, and under, the floor boards, which not only makes it more convenient if the piping should ever, for any reason, need to be uncovered, but also assures that it will be supported by the joists which may be notched out as near their points of support as is possible. Vertical pipes are usually run in hollow partition walls. Wherever possible it is preferable to have the gas piping exposed to view.

Piping may be laid level, but if not it should be sloped toward an outlet where it can be properly dripped, that is, where any condensation formed might be conveniently drained off.

After a system of piping has been properly installed, it needs very little attention under normal conditions. In time a certain amount of scale may form, and if this collects at any point the area will be reduced and the pressure lowered, thus causing a complaint from the consumer that the supply has been insufficient. By shutting off the gas at the meter and forcing air through the pipes by means of a hand-pump, these obstructions can usually be removed. The decision as to where each outlet should be placed to afford the proper distribution of light, should be made by an illuminating engineer. Of course, there are innumerable little houses where the small rooms, usually square or oblong, do not allow fixtures other than central pendants or side wall brackets to be installed, and in these cases it is of little importance that the various outlets are located by one who, perhaps, knows little or nothing about lumens, foot-candles, glare, coefficients of reflection, etc. On the other hand, there are thousands of larger residences, apartment houses, commercial buildings, and school houses, where the size of the rooms does not limit the type or location of lighting fixtures. In structures such as these, the location of the light sources should rest with one who is familiar with the principles of illumination.

The writer's attention was recently called to an instance where, in an operation of the better class of dwellings, the living room was very poorly illuminated, due to the improper location of the outlet. By placing the fixture a few feet to one side, the lighting could have been greatly improved. This is a case where good illumination was evidently sacrificed in order to do away with running the extra pipe extension.

In piping houses for gas, the outlets should be properly located and the piping run to the outlets, instead of, as is the rule in so many cases, locating the outlets according to the easiest and least costly system of piping. If the members of the Illuminating Engineering Society when the opportunity presents itself, will emphasize this point, better illumination will result in many instances.

The cost of installing a complete, modern system of gas piping, if put in at the time the building is erected, varies from about one-eighth of 1 per cent. to 1 per cent. of the total cost of the building. These figures are based on the analysis of a large number of cases, ranging from an ordinary residence to large office and commercial buildings.

KNOWNS AND UNKNOWNS IN THE LIGHTING OF SMALL INTERIORS.*

BY J. R. CRAVATH.

Synopsis: This paper attempts to summarize briefly the principal known facts to be observed in planning the lighting of small interiors. Some of the points in controversy and undetermined are stated and the author's views are given as to a safe course to pursue pending the acquisition of more definite knowledge on these points.

In attempting to summarize in this paper some of the principal known and established facts in the illumination of small rooms I can necessarily present but one point of view, my own, because no two workers in the field would be likely to agree as to just what can be considered "known" what "questionable" and what "unknown." In my presentation of this matter I shall endeavor to take what appears to me a rather conservative attitude. In doing so I shall doubtless incur the criticism of some for having gone too far and that of others for not having gone far enough. Much that will be said here concerning the lighting of small interiors applies equally to all classes of interior lighting.

Lighting of small interiors affects the comfort, convenience and pleasure of far more people than any other class of lighting.

This subject will be taken up under three headings as follows:

(1) Comfort, efficiency and safety of the eyes.

(2) Physical efficiency in the utilization of the light generated.

(3) Esthetic or artistic effects.

Of these three the first relating to comfort and efficiency of the eyes is by all means first in order of importance. As to the others, whether efficiency in light utilization or artistic effect is the most important depends altogether on the purpose for which the small room is used. For the benefit of those who might say that psychology should be introduced somewhere in my general

* A paper read at a meeting of the Chicago Section of the Illuminating Engineering Society, April 22, 1915.

classification, it may be pointed out that psychology undoubtedly enters both into questions of comfort and efficiency of the eyes and into esthetic effects.

COMFORT AND EFFICIENCY OF THE EYE.

As a broad principle the comfort and efficiency of the eye depends upon the distribution of brightness within the range of vision.[1, 2, 18] It should be kept constantly in mind that whatever is said in this paper regarding brightness values which are good or bad for the eye assumes that the brightness under consideration is actually within the range of vision. The eye is concerned only with what it sees. Consequently if bright light sources are not within the range of vision they are out of consideration except for the reflection from them which may come from glossy surfaces which are within the range of vision.

What is said here as to the known effects of light upon the eye under a given set of conditions does not necessarily apply to all individuals because there is fully as much difference between what different eyes will stand as there is between the physical strength and endurance of different persons. What is said here is intended as applying to most of the people most of the time.

In the discussion of brightness values in this paper figures will be given both in candlepower per square inch and in "apparent foot-candles." An apparent foot-candle of brightness will be here used as meaning a brightness equivalent to that of a perfect mat diffusing and reflecting surface illuminated to an intensity of 1 foot-candle. It is 452 times the candlepower per square inch. While this is not yet a generally accepted method of expression I believe it is valuable in conveying a more definite mental picture than an expression in candlepower per unit area to those of us who are constantly dealing with illumination as measured in foot-candles.

Taking certain well known natural conditions as a starting point, it is known that a clear blue sky having a brightness of about 2 candlepower per square inch, or 904 apparent foot-candles, can be faced with entire comfort when it fills the upper part of our field of vision outdoors in the open or near a window, provided the lower part of our field of vision consists of green or gray fields or some equally dark surface. It is only when the

lower part of our visual field is filled with light reflected from snow or desert or light colored roadway that a normal person will experience discomfort facing a blue sky. However, if one faces a small patch of this same blue sky and from the rear of a small narrow office so that it stands as a bright patch amid dark surroundings, it may be put down as a known fact that the majority of people will experience discomfort within an hour or two if not sooner.

The second known fact in connection with the comfort of the eye and brightness of surfaces is that, even though a given surface may be comfortable to face continuously under bright surroundings, a surface of the same brightness if presented so as to be in sharp contrast with its surroundings (that is very much brighter than its surroundings) may cause decided discomfort if continually within the field of vision for some time.

In the artificial lighting of small rooms it is well known from the personal experience of many observant people that the exposure of certain undiffused light sources, if of sufficient candlepower, to adequately light the room according to modern ideas will cause discomfort to the eyes. This is assuming, as said before, that those bright sources are exposed to the eye for some considerable period.

Beginning at the top of the list the brightest source of artificial light with which one commonly deals in the lighting of small interiors is the tungsten lamp with a brightness of over 1,060 candlepower per square inch, or about 479,000 apparent foot-candles, or more. The gas-filled lamp is probably 2,500 to 3,000 or more candlepower per square inch, or 1,130,000 to 1,350,000 apparent foot-candles. As to the bad effect of exposed lamps of such brilliancy in small rooms where persons must face them continuously there is practical agreement among illuminating engineers and oculists, although it is by no means known or agreed just what is the real cause of the discomfort or fatigue which is commonly experienced.

Coming down from tungsten lamps to sources of less intrinsic brightness there is the carbon lamp which is still uncomfortably bright, namely, from 400 to 600 candlepower per square inch, corresponding to 180,000 to 270,000 apparent foot-candles.

The Welsbach mantle of about 31 candlepower per square inch, or 14,000 apparent foot-candles, may also be included among the uncomfortably bright sources without much question.

Next comes a class of bright surfaces or light sources about which there has been some controversy. These are the light sources just enumerated when enclosed in diffusing glass.

A frosted tungsten lamp bulb has a brightness of 2 to 8 candlepower per square inch, or 900 to 3,600 apparent foot-candles. In this case there is an approach to brightness values comparable with the sky in its various aspects. However, I have already shown that sky brightness amid comparatively dark surroundings can be uncomfortable, and in this case the surroundings in an artificially lighted room are very dark compared with the frosted tungsten lamp.[1]

The evidence seems to be steadily accumulating against the use of exposed sources of this order of brightness where they must be faced continuously. To the personal experience of the many who find it unpleasant to sit and face such sources there have been added the investigations of Dr. C. E. Ferree of Bryn Mawr College who, by the use of his method of testing for eye fatigue,[3, 4, 5] has been able to reduce to a quantitative basis some observations which heretofore could be made only in a somewhat haphazard fashion. While it is true that the work of Dr. Ferree's test so far has been confined largely to his own laboratory supplemented by some confirmatory work[6] done by myself in 1914, I personally believe that as a result of these rather extensive experiments it may be put down as one of the knowns that, in the lighting of small rooms where the exposed sources are such as to have a brightness of over 1 candlepower per square inch or 452 apparent foot-candles, trouble from eye fatigue and discomfort will follow from continuous work with the light from such concentrated sources shining in the eyes.

Below 1 candlepower per square inch or 452 apparent foot-candles brightness for the exposed light sources one enters a region of uncertainty and controversy as to the effects on the eye. The heavy pressed bowls used for semi-direct lighting at the present time as actually used in the lighting of small interiors generally have a brightness from about 2 candlepower per square

inch, or 904 apparent foot-candles, down to about 0.075 candlepower per square inch, or 34 apparent foot-candles. With pure indirect lighting the brightness of the ceiling (which is the visible source of light) usually falls between 50 and 4 apparent foot-candles in small rooms.

The researches of Dr. Ferree[3] seem to indicate that there is some eye fatigue when facing units of 0.71 candlepower per square inch, or 320 apparent foot-candles in a room with light colored walls. Extensive tests which I made last year[6] indicated no more fatigue with the subjects facing a brightness of 0.35 candlepower per square inch, corresponding to 156 apparent foot-candles, in the shape of certain semi-direct lighting bowls than was experienced with a pure indirect system. It is of course obvious that the pure indirect system offers the minimum of surface brightness with which it is possible to accomplish artificial illumination at the present time. As far as present information goes from the tests cited and from experience it seems probable to me that a brightness of about 0.5 candlepower per square inch, or 230 apparent foot-candles, for semi-direct or luminous bowl indirect lighting equipment for small rooms should be about the maximum limit. Some semi-direct bowls at the present time offer considerably greater brightness than this to the eye, while others fall well under the limit.[7]

What has just been said applies to semi-direct and luminous bowl fixtures of the sizes commonly necessary to light a room. If the bright area exposed is small, however, so that the total candlepower is low the limits just suggested may be comfortably exceeded.

So far in considering this subject of the effect of the brightness of the exposed light sources upon the eye in small interiors only the effect of the light which goes directly from the sources to the eye has been considered. However, there is another class of effects closely allied to the first, namely, the reflection from smooth or polished surfaces, one example of which is commonly known as "glare from paper." One of the thoroughly known facts is the annoyance and eye-straining effects of this glare from paper, polished tables, and all smooth polished surfaces. This glare is simply the result of reflection from the original

light sources. It is obvious that whatever is done to diffuse the light from such sources—that is, to enlarge the area from which the light comes—and reduce the brightness will be beneficial in reducing the glare from paper. The same things that are beneficial in diffusing the light from exposed surfaces for the comfort of the eye are beneficial in reducing this glare from paper.

In some cases as with a shaded reading or desk lamp the source of light is shaded from the eyes of the occupants of the room, but is not shaded from the papers which are being read. In such cases the position of the lamp with reference to the paper and the eye is all important as the eye should not be in a position to receive glare from the page. The correct position may or may not be easy to attain.

It may be taken as fully known and demonstrated that diffused light is best for reading and working on papers and polished surfaces. Much of the pleasing quality of daylight for reading is due to its diffuse character. For sewing on cloth where the direction of the light is such that shadows do not interfere, direct light is equally satisfactory.

The result of hundreds of tests on many individuals [9, 10, 11] on the amount of light preferred for reading shows that the majority asked for a lower intensity with diffuse than with direct or more uni-directional lighting. In my opinion, considering the method of making these tests, these results should be interpreted as meaning that the diffuse lighting is more satisfactory rather than as indicating that one can with safety plan for less illumination with diffused or indirect systems. When the quality of illumination is not satisfactory most people ask for more quantity regardless of the real trouble.

It is established beyond controversy that a purely localized illumination is not satisfactory.[3, 19] The eye has not been evolved under conditions such as prevail with a bright area in the center of the visual field with the surroundings dark. This is the condition that one finds with purely localized light such as is furnished with an opaque shade concentrating light on some spot upon which we are working with the eye; the rest of the room being in darkness.

If we cannot get all our light for working purposes from

diffusing sources such as day skylight and indirect artificial light we should at least provide as large a portion of the total light in the shape of general diffuse light as possible. If necessary for reasons of economy this can then be supplemented by such amount of localized light as is necessary for the particular purpose in hand. The presence of a considerable amount of general lighting, especially if it is well diffused, greatly enhances the comfort with which work can be done under the localized light.

In the lighting of small offices, daylight coming through windows usually has one important advantage over diffused artificial light coming from a ceiling, namely, the direction of the light. Even with the best diffused indirect artificial light or natural skylight from windows there is some trouble from specular reflection or glare from paper. It is easier to avoid this specular reflection when the light is coming from one side as it does from a window than when it comes from above. In a large interior these difficulties largely disappear because of the large expanse of lighted ceiling which increases the diffuse character of the light received upon a page.

Those who would put unshaded bracket or table lamps almost in the line of vision in a small room should remember that it has been well demonstrated in connection with experiments on street lighting both by Mr. A. J. Sweet[12, 13] and by Mr. Preston S. Millar[14] that, when a lamp is brought within a range of about 25 degrees of the object which one is looking at, it has a blinding effect which necessitates more illumination on the object in order to see it with equal clearness. This effect increases as the light is brought nearer to the line of the center of vision.

When the edge of a lamp shade is below the level of the eye all that is necessary to guard the eye from the direct light of the filament is to have the source slightly above the edge of the shade. When, however, the edge of the shade is above the eye of a person sitting in the room much more care must be used as to the correct position of the source with reference to the shade or reflector. A lamp at ordinary chandelier heights can only be properly shaded when the edge of the reflector protects the eyes from direct rays emanating from the lamp at angles in excess of about 25 degrees from the vertical. If this rule is adopted the

eyebrows of the average person will shade the eyes when the person approaches within the 25-degree zone and the reflector will shade the eyes when the person is outside of the 25-degree zone. Of course, this angle will vary somewhat for different individuals, but 25 degrees is a good working average.

As to effect of color on eye efficiency and comfort little is known save that a nearly monochromatic or one color light like the mercury vapor is better for work on fine details.[15, 16]

In the lighting of small offices and desk lighting in residences shadows play an important part in determining the satisfactory or unsatisfactory character of the illumination from an ocular standpoint. The more diffused the lighting the greater the freedom from sharp shadows. If semi-direct or indirect lighting with luminous bowl fixtures is employed the minimum amount of shadow is obviously obtained when the brightness of the bowl does not exceed that of the ceiling. The more the brightness of the bowl exceeds that of the ceiling the greater the noticeable shadow to cause annoyance. Annoyance from shadows is not serious, however, until the light direct from the bowl exceeds 15 per cent. of the total, as determined by Mr. T. W. Rolph.[17]

The brightness of the fixture bowls in semi-direct lighting of offices and most work rooms is limited more by the importance of avoiding shadows than by the brightness values which will be comfortable to face. In other words, it is usually permissible to use a somewhat brighter bowl in a living room or dining room than in an office.

EFFICIENCY OF LIGHT UTILIZATION.

By efficiency is meant the percentage of the light generated which is delivered on a plane level with a common table top, 30 inches (76.2 cm.) from the floor. This depends on: (1) The color or reflecting power of ceiling, walls and floor; (2) the shape of the room; (3) the reflector and globe equipment; (4) the locations of the lamps.

Color of ceilings, walls and floors may, it has been demonstrated by Lansingh and Rolph, make a difference of over 4 to 1 in the illumination. When dealing with common colors, however, I think a difference of 2 to 1 would be the ordinary range unless

it is attempted to use indirect lighting with a dark ceiling when the ratio would be very high.

A low square room will show the least loss of light by absorption and a high narrow room the greatest. In other words, the greater the wall area in proportion to the floor area the lower the efficiency.

The globe or reflector equipment has a great influence on efficiency, but comparative figures on this must necessarily apply to only one given set of conditions because the comparative rank of the different equipments will change with room colorings and lamp locations. For example, an indirect system obviously is more affected by ceiling color than a direct system.

As to locations of lamps a central location is more efficient than locations near the walls.

A table covering efficiencies even for the commonest of practical conditions would be too bulky for ordinary use. However, the following will serve to give some idea of the usual ranges of efficiency figures for certain conditions.

For a typical room 15 feet (4.57 m.) square by 9 feet (2.74 m.) high, assuming a light ceiling in each case the light falling upon the working plane in percentage of total light emitted by the lamp, with the light all generated by a tungsten or gas mantle lamp at one central outlet will be about as Table I:

TABLE I.

Efficient bowl-shaped opal or prismatic reflectors at ceiling	45 to 60 per cent.
Frosted enclosing globe at ceiling	25 to 40 per cent.
Bare unshaded lamp near ceiling	30 to 45 per cent.
Indirect, mirrored reflectors	25 to 35 per cent.
Indirect, white enameled reflectors	21 to 31 per cent.
Mirrored reflector, at ceiling, deep	70 to 80 per cent.
Aluminum finished metal at ceiling, deep	45 to 60 per cent.
White enameled metal at ceiling	45 to 60 per cent.

The foregoing figures apply to clean lamps and reflectors.

In office buildings of our larger cities where soft coal is used, a decrease of illumination due to accumulation of dirt may be figured at about 11 per cent. in one month in all systems where reflectors are employed.

ESTHETIC OR ARTISTIC EFFECTS.

This is the most difficult part of the subject in which to lay down definite laws and establish facts for the reason that individual tastes and opinions vary so greatly. The old saying that "there is no accounting for tastes" is simply one way of expressing the difficulty of formulating any rules regarding matters which involve individual opinion as to what does or does not "look well." The most that can be done is to make a few observations as to the observed trend of public opinion in some of the more important matters relating to lighting small interiors.

First it must be recognized as a general principle that a large number of people will not consider that any arrangement, style or design looks right unless it corresponds closely with present conditions. With another class of people novelty and change rather than adherence to present conditions are sought after.

On the question of color it must be recognized that for generations artificial lighting has been done with illuminants rich in yellow and deficient in green and blue. The only exception to this is the Welsbach gas mantle and to judge from the statements made at the last meeting of our section by Mr. Luther that type of mantle is most popular in the lighting of small rooms which tends to bring out the reds and yellows and suppresses the greens and blues. It may be taken as established that any light which does not have a sufficient percentage of red and yellow in its composition or has too much green and blue is likely to create a ghastly appearance of hands and faces. It also renders unattractive rugs, carpets and wall paper in which yellow and red hues are prominent.

It is a matter of controversy and personal taste and opinion as to whether the gas filled tungsten lamp and amber tint Welsbach mantle give a light which needs modification toward the yellow in order to be most acceptable for common use in residences. As these sources are considerably more yellow than any kind of daylight it seems probable that a part of the objections to these illuminants is due to the fact that they are whiter than the artificial illuminants to which we have been formerly most accustomed, and that some of these objections will gradually become less as the whiter types of illuminants become more common.

Nevertheless it must be accepted as demonstrated that the yellow illuminants of the older types or the present illuminants modified by globes or ceiling tints to make them more yellow produce some very agreeable effects on complexions and on some kinds of room furnishings. With direct lighting the color can be easily controlled for most practical purposes by the use of the proper glassware and for indirect lighting the color of the ceiling largely influences the ultimate results. Such color modifications, however, always means loss of efficiency and allowance must be made for this.

The direction and character of shadows have important effects on objects in a room and these shadow effects have to be more considered in small interiors where the sources of light are fewer in number than in large interiors. Where light is largely unidirectional, that is, direct from a small bright source with insufficient diffuse lighting to modify it, the sharp shadows which result help to bring out wrinkles and give a harsh appearance to complexion and features. Diffuse lighting either from ceilings and walls or from windows and skylight does not in practice do away entirely with shadows, but rather softens them to an extent which renders the general appearance of persons and objects much more pleasing.

As to whether there should be a visible source of light on the lighting fixture there is no agreement. Many like to see a little light coming from the fixture itself for decorative purposes. Others care nothing about this.

To some the localized lighting effect produced by a dome over the dining room table or by a table reading lamp which lights one spot brightly and leaves the rest of the room somewhat in shade produces a cozy effect which is pleasant. Others feel that they cannot feel cheerful without having the whole room brightly lighted.

Objections have been raised to indirect and semi-direct lighting that the ceiling is too bright and that it reverses the old order of things too much. Others seldom think of this effect. Tastes in these matters are largely a question of environment and education.

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PROPOSALS RELATIVE TO DEFINITIONS, STANDARDS AND PHOTOMETRIC METHODS.*

BY HERBERT E. IVES.

A series of studies in photometry, more particularly in connection with lights of different color, has led the writer to suggest the adoption of a new standard of luminous flux and of a definite photometric method in heterochromatic photometry. The steps leading to these suggestions, and the arguments in favor of their adoption, are to be found in the papers listed in the bibliography at the end. What is here presented for publication in the TRANSACTIONS of the society is a specific set of suggestions in tabular form, to be taken up later for consideration, if desired, by the appropriate committee of the society.

DEFINITIONS.

Power consumed by a light source $= \mathrm{P}$; expressed in watts, a portion of which is dissipated by radiation, the remainder by conduction and convection.

Power radiated by a source $= \mathrm{R} = \int_0^\infty \mathrm{R}_\lambda \, d\lambda =$ power emitted by a light source in the form of radiation between wave-lengths 0 and ∞, expressed in watts.

Radiation efficiency $= \frac{\mathrm{R}}{\mathrm{P}} =$ ratio of the power dissipated as radiation to the total amount of power consumed by the source. (A pure numeric.)

Luminous flux $= \mathrm{F} =$ radiant power evaluated according to its capacity to produce the sensation of light.

Light evaluating factor or stimulus coefficient of any radiation is the ratio of the luminous flux, in its appropriate units, to the radiant power producing it, in its appropriate units.

The luminous efficiency of any radiation $= \mathrm{L_R} =$ the relative capacity of the radiation to produce the sensation of light, com-

* A paper presented at a meeting of the Philadelphia Section of the Illuminating Engineering Society May 21, 1915.

pared with the capacity of the same quantity of radiation of the maximum possible light producing capacity . (A pure numeric.)

The luminous efficiency of any radiation is the mean value of the luminous efficiencies of its component monochromatic spectral radiations. These latter are specified by the luminosity curve of the normal equal energy spectrum, of maximum value unity. The spectral luminosity curve is obtained by the standard photometric method for colored light photometry.

To a close approximation the spectral luminosity curve is represented by the expression:

$$L_\lambda = A\left(\frac{R_1}{\lambda} e^{1-\frac{R_1}{\lambda}}\right)^\alpha + B\left(\frac{R_2}{\lambda} e^{1-\frac{R_2}{\lambda}}\right)^\beta + C\left(\frac{R_3}{\lambda} e^{1-\frac{R_3}{\lambda}}\right)^\gamma$$

where

$A = 0.999$	$R_1 = 0.556$	$\alpha = 200$
$B = 0.04$	$R_2 = 0.465$	$\beta = 400$
$C = 0.095$	$R_3 = 0.610$	$\gamma = 1000$

Total luminous efficiency of a light source $= L_T =$ the relative capacity of the power applied to a light source to produce the sensation of light, compared with the capacity of the same quantity of power in the form of radiation of maximum possible luminous efficiency. (A pure numeric.)

Units.—Luminous flux is connected to radiant power by a numerical evaluating factor. The unit of power is the watt. The present arbitrary practical unit of luminous flux is the lumen. The light evaluating factor or stimulus coefficient is consequently expressed in lumens per watt. If for this evaluating factor is taken the *luminous efficiency* as above defined, the unit of luminous flux is the same as that of radiant power or applied power, namely the *watt.*

In the symbols proposed:

$$P \times \frac{R}{P} \times L_R = P \times L_T = F.$$

In order to go over to the watt as the unit of luminous flux it is necessary to know the:

Mechanical Equivalent of Light = the value of the lumen in watts of luminous flux.

(The lumen is approximately 0.00162 watt of luminous flux, or light watts.)

(The terms "specific consumption," "specific output," etc., involving relationships between watts and lumens, are superseded by the method of defining luminous efficiency, and by the adoption of the watt as the unit of luminous flux.)

The quantities derived from luminous flux, *e. g.*, illumination, luminous intensity and brightness, are to be defined as at present, with the necessary substitution of the watt of luminous flux for the lumen wherever occurring. It is suggested that the new unit of luminous intensity on the watt basis, might be called the "pyr."

METHODS OF MEASURING LIGHTS OF DIFFERENT COLOR.

Visual Method.—The visual method is specified by the type of photometric instrument, the conditions of its use and the choice of observers.

The instrument shall be the flicker photometer, in which the photometric field shall be two degrees in diameter, with a surrounding field of as large diameter as feasible, of approximately the same brightness. The photometric field shall be maintained at an approximately constant brightness of 0.013 watt of luminous flux per square meter per unit solid angle (the brightness of a white mat surface under an illumination of 25 meter-candles, present practical units).

Precision measurements should be made by a group of at least fifty observers who possess no marked abnormalities of vision, or by a group of not less than five whose average readings are the same as those of the larger group.

(A group of five or more may be considered as constituting a normal eye group when their average value on the following color difference is equality.

Color A—72 grams potassium dichromate + water to 1 liter.

Color B—53 grams cupric sulphate + water to 1 liter.

These solutions at 20° C. to be contained in matched clear white glass tanks, 1 centimeter in thickness, and measured by the instrument and conditions above, over a standard "4-watt" carbon lamp.)

Physical Method.—The characteristics of the average eye may be incorporated in a physical artificial eye, consisting of a radiometer whose spectral wave-length sensibility curve is that of the average eye.

(A close approximation to such an artificial eye is furnished by a non-selective radiometer, over which is placed the following solution, in a thickness of 1 centimeter:

Cupric chloride	60.0 grams
Cobalt ammonium sulphate	14.5 grams
Potassium chromate	1.9 grams
Nitric acid (1.05 gr.)	18.0 cc.
Water to	1 liter)

This solution should be protected from overheating by the interposition of a layer of clear water at least 2 cm. thick.

SUGGESTIONS FOR RECOMMENDATIONS TO BE MADE BY THE SOCIETY.

The establishment of the watt as the unit of luminous flux, and the development of the precision physical photometer, depend upon the exact determination of the spectral luminosity curve of the average eye. The luminosity curve and the ratio of the lumen to the watt have been determined with considerable accuracy, but to meet the needs of the future they should be even more definitely fixed.

It is suggested that determinations of these factors would be most appropriately made by the Bureau of Standards, and that, therefore, the Illuminating Engineering Society recommend to the Bureau as specific problems of value to the science of light measurement:

1. A determination of the average spectral luminosity curve by measurements upon at least fifty individuals, by the photometric method above specified.

2. A determination, using the results of the luminosity curve study, of the ratio of the lumen to the watt of luminous flux.

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ILLUMINATING ENGINEERING AS A BRANCH OF TECHNICAL INSTRUCTION.*

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Synopsis: Through the efforts of the Committee on Education the amount of instruction in illumination given by various technical schools and colleges has been gathered into a most interesting report covering its investigations into the field of college instruction along these lines. Somewhat with the idea of supplementing the summary of this committee and also for the purpose of presenting a more detailed description of the work which has been carried out at two of the institutions investigated by the committee, this paper has been prepared with special reference to the illumination courses given at different times during the past three years at the Sheffield Scientific School of Yale University and at the University of Pennsylvania. Among the various features included in the paper are the points which give to illumination a wide range of interest for students in practically all courses whether academic or technical. After describing methods used in the work for undergraduate and graduate students at these two institutions, general conclusions are tentatively drawn as to the best methods to follow in planning out such work, and the views of heads of electrical engineering departments in leading universities are quoted in their bearing on this general subject.

A number of plans have been developed during the past year or two for broader general education along the lines of illumination. These plans have included various movements instituted by the Illuminating Engineering Society typified, for example, by the formation of the following committees: (*a*) Committee on Education. (*b*) School Lighting Committee. (*c*) Committee on Popular Lectures. (*d*) Committee on Lighting Legislation. (*e*) Exhibition Booth Committee (Gas). (*f*) Exhibition Booth Committee (Electric). (*g*) Committee on Reciprocal Relations with other Societies.

The Committee on Education also has for one of its objects

* A paper presented under the auspices of the Committee on Education at a meeting of the New York Section, Illuminating Engineering Society, May 13, 1915.

an effort to promote the study of illuminating engineering in the technical schools and colleges as a general or specific branch. It seems particularly appropriate, therefore, to present under the auspices of this committee a brief summary of the work which has been done at two representative universities during the past few years in offering to undergraduate and graduate students work pertaining to lamps and artificial lighting.

Prof. Chas. F. Scott of the Sheffield Scientific School of Yale University has made the statement that illumination has a far wider scope and the college has a far greater opportunity in illumination than the training of a few specialists. Adding to this, he continues, "There must be specialists for research, invention and development, as well as expert illuminating engineers, but their number is infinitesimal compared with those who apply lamps and use lighting." These statements at once classify the teaching of illuminating engineering into two broad divisions, *i. e.*, work especially adapted to those few who plan to become experts either in research or practical illuminating engineering, and, in contrast, those who must apply lamps and use light, typical of practically every student who enters a university when interpreted in a liberal way.

WIDE RANGE OF INTEREST.

It might seem at first thought that to make the following notes fairly definite, reference should be made in particular to electrical engineering students who would ordinarily have more than a passing interest in illumination on account of its close alliance with electrical engineering activity in general.

On the other hand a student in architecture will ultimately be confronted with the problem of the arrangement and number of lamps in the building over which he has supervision; the medical student should be interested in the relation of proper lighting to the human eye; the mechanical engineer, who may be a works manager in an industry, should be concerned with proper illumination in its influence on the comfort, wellbeing and working efficiency of his employees; the director of municipal engineering may be confronted with the proper lighting of city streets; the electrical engineer as well as the gas engineer, is vitally concerned with the principles of illumination because artificial light-

ing may be looked upon as the basis of the electrical and gas industries; and, lastly, the average citizen, through the proper lighting of his own home or his office as the case may be, unless posted, is at the mercy of others in the planning of such lighting, which from common experience is more apt to be wrong than right.

To quote Prof. Scott in this connection, and in summarizing these different branches of engineering study, it is only necessary to point out in passing that a large majority of students coming under these various heads do not expect to become illuminating engineers or lighting experts, but in every case should be given a training in the fundamentals of illumination, and in the relations of proper lighting to their professions.

ELECTRIC MACHINERY ANALOGY.

This statement has an analogy in a great deal of engineering work. Thus in the study of electric machinery, the general tendency has been to modify the old attitude which looked to the training of designers, and rather to concentrate more and more attention upon the principles which govern operation and intelligent application of electrical aparatus This does not imply that designers are not needed, but merely emphasizes the much larger number of men who go into the operation and application side of engineering than in designing work.

In like manner, men are required for research and development of lamps and new methods of applying lamps, while on the other hand a much larger number of men is concerned with the way these lamps should be applied in practical every day cases, due to the relation of such lighting to their own comfort, convenience or efficiency as workmen.

THREE GROUPINGS OF THE SUBJECT.

Prof. Scott advances the idea that one way to interest students in illumination is to get them to observe lighting conditions in the study room, class room, lecture hall, public hall, store and street, and to analyze the methods of this lighting and the results which the lighting produces, always endeavoring to compare these with ideal conditions. What constitutes "ideal" conditions in various cases is a subject which the student should always be asked to consider carefully. He has further presented three

ways in which the subject may be given to college students, as follows:*

(*a*) For students in all departments, a few illustrative lectures presenting important facts of illumination in relation to different phases of life and indicating that the questions of lighting are not to be decided haphazardly; that illumination is a science; and, above all, that there are experts from whom advice can be secured.

(*b*) For students in architecture, medicine and engineering in general, courses covering the requisites of good lighting, the kinds of lamps and their application.

(*c*) For those students who expect to become experts in this particular field, an advanced and special course.

WORK AT THE SHEFFIELD SCIENTIFIC SCHOOL.

At the Sheffield Scientific School of Yale University the opportunity presented itself, and in making the effort to interest the students of various courses in illumination Prof. Scott followed several methods. One of these was to assign to the junior students, in their seminar course, the topic of shop window lighting, for example, requiring each student during a given week to observe as many shop windows throughout New Haven as he could conveniently see, and to report specifically on several instances of good and bad lighting which had come under his observation. This scheme resulted in excellent returns; was productive of many valuable points brought out in the seminar hours; and increased the powers of observation on the part of the student, who came to observe the lighting effect in various places where he happened to be, more or less as a matter of course.

At these seminar hours the students also presented various papers on lamps and lighting which were prepared beforehand with the aid of articles and books in the reading room, and these papers were discussed and commented upon in such a way that valuable and interesting points were often brought out to better advantage than could well have been accomplished by other means.

In another case the students were asked to prepare a statement of the lighting in their study rooms either in the dormitory or private boarding house, this report to contain a plan and elevation of the room or desk showing the general arrangement of lamps, together with a summary of the various items which the

* *Lighting Journal*, vol. II, p. 73, April, 1914.

student had observed in connection with the lighting effect. These reports proved both interesting and helpful, and in quite a

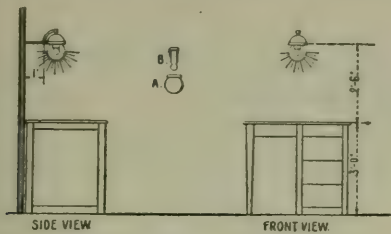
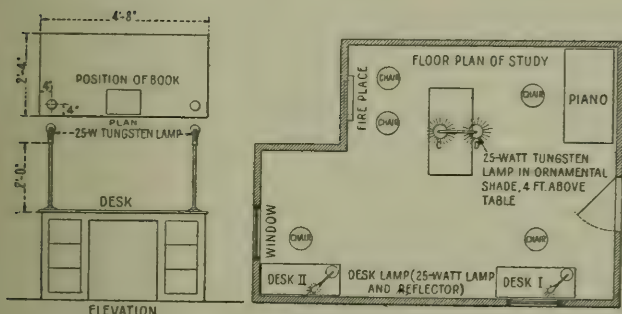
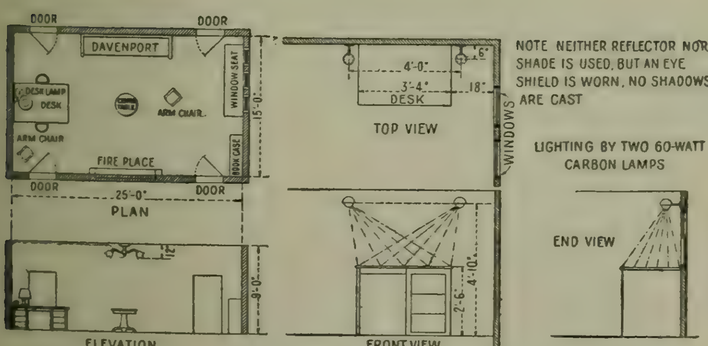


Fig. 1.



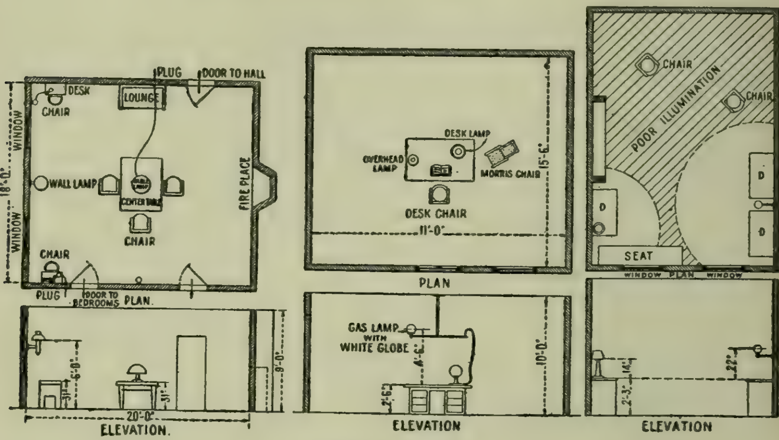
Figs. 2 and 3.



Figs. 4 and 5.

few cases led the student to see that certain very bad conditions existed which they had not before realized, and also to inquire as to the best ways for remedying such conditions. Figs. 1 to 8 indicate typical diagrams which were handed in as a result of

this plan, and the following summary of the points which were brought out by these students in their own words with regard



Figs. 6, 7 and 8.

to the lighting of their rooms is of interest in connection with the diagrams and the general subject.

Fig. 1.—These views give an idea of the illumination in my study room. My desk is 3 ft. high. Directly 3 ft. above, mounted on a horizontal fixture 1 ft. in length, is an inverted lamp burning artificial gas. This lamp consists of the inverted fixture as shown, an inverted mantle, a globe marked B, and an outer globe marked A. The chief difficulty seems to rest in the regulation of the flow of gas. The part directly above the mantle generally becomes clogged with soot. The outer globe A, which was probably made for a shade, was found to cut off too much of the light. Now I merely use the lamp with the smaller globe B, which affords a more intense light.

Fig. 2.—Light is intense enough and dark shadows are avoided. Also there is no glare on the paper. Pretty satisfactory for studying, but lamps are too low for general illumination, as they are directly in the line of vision.

Fig. 3.—Illumination is sufficient because very little work is done except on desk areas, which receive strong light from desk lamps. Moreover, lighting aims to be ornamental as well as useful in a study and lounging room. Working plane is not illuminated with entire uniformity, but this is not necessary where work is concentrated on two small areas. However, there is sufficient light throughout room to allow of ordinary intercourse and affairs at any point in it. Glare from desk lamps is avoided by turning the intensive reflectors away from the eyes and by use of non-glazed paper. The average foot-candle intensity is only 1, but

the light is so concentrated on the working area as to be fully sufficient for all working purposes. Thus if the whole working plane were to be thoroughly lighted, the intensity should be about 3 foot-candles, or three times as much. Hence the arrangement is economical.

Fig. 4.—The lighting consists of three 40-watt, 110-volt tungsten lamps; two in a central fixture overhead, with a mounting height of 1 ft., and one desk lamp, its energy being supplied from the central fixture. The working plane is 3 ft. above the floor. The regular intensive type prismatic reflectors are used in the central fixture, while the desk lamp has a green glass shade. The central lighting fixture is mounted in the center of the plaster ceiling. The room is sufficiently lighted, the desk lamp alone supplying sufficient light for studying and reading. Except for the extreme corners, the whole room is rather uniformly lighted, though the working plane could not be said to be uniformly lighted throughout owing to the arrangement of the fixture. There is more or less glare on the desk, due to papers, which is avoided by dispensing with said papers and moving the desk lamp.

Fig. 5.—Neither reflector nor shade is used, but an eye shield is worn. No shadows are cast. Lighting by two 60-watt 110-volt carbon lamps.

Fig. 6.—The lamps used are all 25-watt tungstens and are eight in number, the fixture on the table taking two lamps. The lamps on the desks are ordinary flexible desk lamps. The reflectors are all intensive. The illumination on the desks is sufficient, but there is a glare from the papers. The table lamp is very poor as it is very intensive and is more ornamental than useful. The lamps about the wall are more for artistic purposes than for real lighting. The economy is very low.

Fig. 7.—For study, and reading close to the desk, the study lamp is sufficient; the lamp overhead, being directly over the desk, does not add much to the light on the desk. For reading away from the lamp, the light is hardly sufficient, even with the overhead lamp. The light is much poorer on the left side of the desk, since the lamp is at the right for convenience. Glare is usually annoying, since my eyes are usually in line with lamp and book; I usually shift the book, but it might perhaps save time to change the lamp. I rarely use the lamp overhead; the mantle usually gives less and less light till a new one is necessary, which is once in every two months or so; I should call the economy about average.

Fig. 8.—The lighting for this room was furnished by gas, burned with mantles. An opalescent globe is used to cut down the glare, but no reflector is used. There are but two of these lamps for the room, being mounted a foot or more above the working surface of the desks. The illumination is sufficient for reading and working at the desks without eye-strain, but at a distance of 3 or 4 ft. from the lamp the illumination is too poor even to attempt to read. Owing to the translucent globe surrounding the mantle, there is no noticeable glare from papers lying on the desks. I think that on account of the necessity of cutting down the

light from the gas lamp, it is a poor type to use for individual lighting, and that it would have been better to have a couple of these mantles in the center of the room equipped with proper reflectors, so that individual lamps would not be necessary.

The foregoing statements taken from a large number of similar opinions represent the ideas of typical senior and graduate students before giving any appreciable attention to the subject of lighting. The various instances cited are selected from written reports of men in both the electrical and mechanical courses and the opinions advanced are of special interest and importance because they show an appreciation of many illumination features, even if expressed in a crude way, which ordinarily are not given attention by the average user of light. The features brought out by these simple reports are also considered important because they indicate how readily a student takes up an analysis of a lighting problem as simple as that involved in the lighting of his own study room after his attention is called to the fact that there is something to analyze.

A summary of these eight opinions indicates that the attention collectively has been directed to items which include intensity, shadows, glare from lamps and reflecting surfaces, general illumination, regulation of gas flow, deterioration, sizes and types of lamps and reflectors, ornamentation versus usefulness, economy and uniformity. To me this has seemed like a considerable return for practically the first inspection of a system often consisting of one gas burner used to illuminate a desk and its books and papers. With a physical conception of these items as a working basis, a course in illumination should easily result in favorable progress when related to the proper combination of such basic items for obtaining good illumination in specific cases.

It is, of course, important to follow up a general report like this on the part of the students with a discussion either in the lecture or class room, and this might possibly be increased to several such talks pointing out the various items which must be considered if good lighting is to result.

ILLUMINATION AND MECHANICAL ENGINEERS.

In my own work given to senior mechanical engineers at the Sheffield Scientific School, in addition to the fundamentals of

electric circuits and machinery, a short time was allotted to a treatment of factory lighting in its specific relation to shop management.

The formation of this part of the work for senior mechanical engineers resulted largely from a conference with a former graduate in mechanical engineering who was employed in the works management side of a Connecticut industry, and who stated on the occasion of a visit to the university, that one of the first jobs which he had to undertake after leaving college was that of improving the artificial lighting in his plant. His request for some kind of information or a reference which might lead him to gain a little understanding of the methods of handling such a problem seemed so clearly to indicate the necessity for at least some work along this line for mechanical engineers that it was decided to incorporate a short course in factory lighting for these men as part of their work in the electrical engineering department. This work involved one lecture and one recitation per week for about three weeks.

COURSE FOR GRADUATE ELECTRICAL ENGINEERS.

About two years ago a specific course was outlined in illumination at the Sheffield Scientific School for graduate students in electrical engineering. This course consisted of classroom and problem work, and also a limited amount of lecture work. The text book used as a basis for the course was Clewell's "Factory Lighting" supplemented by frequent explanations and discussions and by a number of practical problems.

The course, given as it was to graduate students, assumed a certain degree of preparation in the physics of light, and emphasized more particularly the practical or application side of lamps and illumination. In a general way the following topics may be considered as representative of the work given: 1. Types and operating features of lamps; 2. Reflectors and their effect on the resulting illumination; 3. The objects to be obtained from a lighting system; 4. Bad features of certain lighting methods; 5. Methods of design, installation and maintenance; 6. Study of the lighting in specific locations, such as offices, drafting rooms, and factories.

The work was covered in one term with two exercises per week, and in addition to the regular time allotted, illumination tests were made in one of the rooms of the engineering building with different types of reflectors so as to check up the predetermined values of illumination intensity which had been calculated for this same room, on a basis of the reflector distribution curves measured by the student.

In addition to the foregoing, the Yale Branch of the American Institute of Electrical Engineers was used as a medium on one or more occasions throughout the year for presenting papers by experts on artificial lighting. For example, Mr. Bassett Jones of New York, and Mr. T. J. Litle of the Welsbach Company, came to New Haven at different times to give talks on the subject of illumination at such meetings. The students also had the opportunity of attending the semi-annual New Haven Branch meetings of the American Society of Mechanical Engineers held at the Sheffield Scientific School, at one of which Prof. Scott and the writer presented discussions on "Factory Lighting." These meetings gave the undergraduate student an opportunity of getting the broader viewpoint of illuminating engineering in its relation to practical work and they proved valuable in their relation to the efforts for promoting a wider interest in the subject.

COURSES AT THE UNIVERSITY OF PENNSYLVANIA.

At the University of Pennsylvania the formation of the new electrical engineering department in the Towne Scientific School in June, 1914 has given an opportunity for certain modifications in the curriculum, one of which has been to establish a definite course in illumination. This work has been planned for senior electrical engineers under a course entitled "Illumination," which extends throughout the first term of the senior year, with one lecture and one recitation per week. The work during the past half year has involved the solution of a number of practical problems, one of these in particular having proved valuable. This problem related to a given floor area with a certain class of work. With a given type of lamp available, the problem was to arrange a lighting plan so as to give satisfactory illumination on the working area.

This scheme of solution has included both the flux of light and point by point methods, and with a number of dark rooms and a portable photometer outfit, the distribution curves of typical lamps and reflectors are later to be taken, followed by the installation of these lamps in a given room. The student is then to calculate the illumination intensity which will result on a basis of the distribution curve which he himself has measured, and this is to be checked up with the actual illumination as measured with the portable photometer, as a part of the regular laboratory course supplementing the recitation and lecture work.

This procedure has worked out thus far in a particularly successful manner because of the interest stimulated by working out a given problem, with the anticipation of following it up by actual measurement. Obviously, also a problem like this will bring out many points, such as the discrepancy between calculated and actual values due to the effect of ceiling and wall reflection and similar items.

To senior mechanical and chemical engineers also some work has been given in factory lighting as a part of their course in the electrical engineering department, this work having been covered in about eight to ten weeks, and involving one lecture and two recitations per week. The interest displayed by mechanical and chemical engineers has been increased by pointing out how good illumination is related to efficiency of production in the kinds of industries in which they are apt to be engaged later.

SOME CONCLUSIONS.

The writer's experiences at the Sheffield Scientific School and at the University of Pennsylvania seem to indicate the wisdom of taking up, first, the physical characteristics of the different types of lamps, and, second, following this by a study of conditions related to the objects to be illuminated, typified, for example, by office or manufacturing spaces, making a careful study of the needs of given cases and then determining which types of lamps are best adapted to the work and how they should be arranged and installed.

The point which is intended here is a little difficult to make clear, but is nevertheless important. A course of this kind if

made entirely descriptive, *i. e.,* based on existing methods of lighting in various kinds of locations, loses force because the average student lacks the experience and perspective to form physical ideas of the items involved and their relative importance. He should, during the course, be given photometric problems in the laboratory and should make illumination measurements under actual installations so that the stimulus produced by the element of personal initiative is added to the interest so often passive in merely descriptive courses.

This general principle is not limited merely to the teaching of illumination, but applies with equal force to many engineering branches, like that, as an illustration, of motor applications where the physical characteristics of motors can to advantage precede the study of the speed and torque requirements of the machinery to be driven These specific items supplemented by numerous problems can then be followed by other more elaborate problems illustrating the selection and application of the motor to the machine.

Briefly, then, the teaching of illumination in its practical aspects seems to lend itself to the same general methods as does that of motor applications, and a rational basis in each case seems to be, in order of treatment:

(*a*) The purpose or object to be accomplished, *i. e.,* the supply of light (or power) as a means to an end.

(*b*) Physical characteristics of lamps (or motors).

(*c*) Physical characteristics of the location (or machine) to which the application is to be made.

(*d*) A study of the conditions involved in the selection and application of the lamp (or motor) in conformity to the preliminary information gained in (*a*), (*b*) and (*c*).

NOT DIFFICULT TO GAIN INTEREST OF STUDENTS.

Taken as a whole, there seems to be no difficulty in gaining the attention and interest of undergraduate students in illumination because it is so intimately related to every day experiences. Quite a number of men come into the office off and on with problems which they run up against, in a dining room, or the hall of a fraternity house, or a church, in connection with which some

friend has asked advice; in nearly every case the man being interested in the accomplishment of a certain result, which had either been a case of bad lighting before, or in which his friends had desired to assure themselves of a good result instead of placing themselves at the pleasure of an architect or a wiring contractor.

It has been found very helpful in this work at the University of Pennsylvania to point out the present status of lighting legislation in the various states throughout the country. To this end the Committee on Lighting Legislation of the Illuminating Engineering Society has been a distinct help, because through their cooperation a summary of the laws in a number of states has been made available in the reading room to which the students go between recitation hours. From the writer's personal experience, it would seem that a great compensation awaits those institutions which undertake work of this kind, even if it be only for accomplishing a better appreciation on the part of the student of what good lighting consists without any regard to his entering illuminating engineering as a special field of later activity. In a few instances, however, undergraduate students have come to look upon the lighting field as one of distinct opportunity.

The recent report of the Committee on Education has gone to show that at the present time the teaching of illuminating engineering in technical schools and universities is not by any means standardized, nor even definite in many cases. This, however, need be no discouragement because electrical engineering education as a whole is far from standardized; in fact it would probably show almost as great a number of discrepancies in a summary of other more or less time honored subjects as now given in the various schools. The main point at issue at the present time is rather to arouse enthusiasm for this work and to place it on a par with other subjects in electrical engineering courses, which either by long usage or an account of actual merit are termed fundamental.

VIEWS OF ELECTRICAL ENGINEERING DEPARTMENT HEADS.

The writer recently addressed personal letters to the heads of the electrical engineering departments in a number of the leading

technical schools and universities to find out how much of a field there might be for the lantern slide talks of the Committee on Popular Lectures before student audiences, in the hope that the opinions expressed would indicate, at least in a general way, the attitude of the men in the educational field to broadening the information of college students along the lines of illumination.

These letters asked specifically for two opinions: (*a*) the amount of theory which should be incorporated in the popular lectures; and (*b*) whether the possible use of such lectures before classes of college students should influence the method of treatment, and in regard also to the field for such lectures before student audiences. Quotations relating to the second item are of interest in showing something of the attitude held at this time by the heads of representative electrical engineering departments and the following paragraphs bearing on this particular phase of the popular lecture movement are quoted because they bring out some interesting points related to the educational problem.

1. I believe the average student will derive more benefit from lectures intended for the public than from technical treatments of the subject. Let us give them the technicalities in the class room. Even there we are inclined to proceed too fast in our effort to cover ground in a short course.

2. I believe that such lectures will be welcome and well received in almost any college in the country.

3. To be successful before the student body, it would be necessary to have the treatment somewhat technical; otherwise they would fail to hold the respect of the students and I do not think that a technical treatment is inconsistent with popular comprehension.

4. If the lecture does not comprise a sound basis on, and in connection with theoretical principles, I think it should not be used before college students. To my mind one of the greatest troubles of our educational system to-day in all its branches is superficiality and the failure to give a thorough grounding in underlying principles. My feeling on this point might be modified somewhat in the case of a lecture which was accompanied by exceptional illustrations both on the screen and on the lecture table.

5. Since, in my estimation, the college student audience is not very different in mental ability from the audience that would be attracted by such lectures, I can see no good reason why there should be any modification of the plan of the lectures on account of the probability that they will be presented in colleges.

There are too small a number of the students in our colleges who are taking courses in illumination. A still larger number are getting

acquainted with the meaning of the term "Photometry" and know the purpose of a photometer in their work in physics. Of these students a large number may have but a hazy recollection of the subject, but I believe those who remember will profit by the lectures. I also believe it to be true that college students, many times, hear with pleasure and profit, from an outsider, the same things to which they give almost no attention if heard in class from their regular instructor.

In regard to the field for such lectures before college audiences, I imagine it is a case in which the demand has to be created. The subject is of the greatest importance and the colleges should be compelled to take heed.

6. As I understand it, your object is general education and, since the college student forms an exceedingly small proportion of the total population of the country, I should hesitate to include modifications in the lecture simply intended for that class.

7. Regarding the field for lectures before student audiences, I think there is a very considerable opportunity for such lectures. For instance, we have an hour each week at which the whole student body is gathered to listen to an address by some outside man, and such custom is followed in a large number of other institutions. There are a great many lectures given before various departments of our colleges and I am sure that if you can enlist a few well known illuminating engineers they would find a large number of invitations to speak before college audiences. When you consider the very large number of colleges in the country, academic as well as technical, and the large number of young men and women who can be reached in this way, it seems to me to offer one of the very best fields of endeavor for the work of your committee.

8. The possible use of these lectures before student bodies should not modify or influence their mode of treatment. The student should obtain the same amount and the same kind of benefit as the practical man in the one or the other business of life. The treatment should be no more technical or theoretical in the one case than in the other. Anyhow I should venture the opinion that for the average student in our colleges and engineering schools much of the highly mathematical theory of some of the subjects presented would be productive of greater results if the time were spent in teaching how to apply the simpler mathematics and the really usable theory. Of course, I am speaking of the average, not the exceptional student.

Such lectures should afford the student a splendid opportunity to get the layman's point of view—to meet him on common ground, and possibly because of his own more complete technical training be the readier in the application of the important principles of illumination, and thus be in position to be of greater service as a practical engineer than he may otherwise have been.

9. As far as the method of treatment is concerned, if these lectures

are intended for popular consumption, and for the purpose of directing the popular mind regarding the proper methods of using lights, which is a large and desirable field to cultivate, no subsidiary use of the lectures, such as using them before college students, should be allowed to influence the method of treatment. That is, if the best effect is to be expected from these lectures as popular lectures, they ought to be planned and executed without any deviation from their primary object.

I don't doubt that there would be a good deal of use for such lectures before arts students in the colleges, and perhaps before the engineering students of the weaker engineering schools, but the popular character of these lectures would probably not injure them for that purpose.

10. It seems to me that unless it is done with extraordinary skill, this kind of thing is pretty sure to scare out a popular audience before the lecture really gets started. Of course, in so far as such lectures were to be used with college students, there would not be so much objection to presenting the theoretical side, but even here I should think it would be as well to confine the lecture mostly to the more practical and to demonstrative features.

11. Lectures before classes of college students by outside illuminating engineers ought to be of great value. I doubt, however, if they would be of such direct value as talks before the general public. The average student feels himself about surfeited with the work he has to do and is not prone to hasten to lectures not required of him unless the subject is somewhat unique or the lecturer of considerable reputation. I would venture to suggest that the best way to get such lectures before the students is to have them given in regular class-room time. In colleges which have a branch of the American Institute of Electrical Engineers, there should be no trouble at all in getting these lectures before the student body. I wish there could be more of this done in this way. If our student branches are to flourish it will only be when they are actively aided by engineers and lecturers from outside.

Again, I believe that these lectures if they are to be successfully given before our students should not go too much into the physics of the matter, but deal largely with the practical side of the question, and should include practical demonstrations, commercial data and the like. The college departments can be relied upon to give the student the theoretical side of the subject. The trouble so often is that we have only time for the theoretical side and can spare little or no time to the practical side.

12. It would seem to me that the method of treatment should be adapted to each individual audience. There is some field in colleges of engineering for such lectures, but I am not able to state what the different colleges offer in this branch of engineering.

13. I believe that lectures more or less popular before college students may have a very beneficial influence on the practical use of light. Such

lectures could be much more technical than those for the general public, for the training in physics prepares the audience for understanding the subject. How much of a field there is for such lectures before student audiences is difficult to say, but I believe that a well illustrated more or less popular talk would prove interesting and draw good audiences at practically all colleges, but particularly those where the work is industrial or scientific in character.

It is gratifying to find, therefore, that in a majority of cases the heads of electrical engineering departments look upon the availability of such lectures as a valuable aid in undergraduate instruction work. Only a few cases have come to my attention where the head of an electrical engineering department looks upon illuminating engineering work as without the range of an ordinary electrical engineering course. This may be due partly to a different viewpoint, or there is a possibility that it may be due to a lack of appreciation of just what has been accomplished during the past three or four years in this important and growing field. It it fortunate, therefore, that the Committee on Education is at work in helping to post such cases on the actual status of illumination at the present time.

It is no discouragement in looking over the report of the Committee on Education, to find that the number of kinds of ways in which lighting and illumination is taught is very diverse both in kind and in amount. On the other hand, it is most encouraging to note that very few of the various institutions investigated can be found which have not in some way outlined work in this field. It is quite possible that if an investigation like this had been made ten years ago practically no work along this line would have been found in the various college schedules; it seems hardly too much to say that a corresponding summary five years hence will indicate almost as much uniformity, at least as regards amount of scheduled time, in the teaching of illumination to undergraduate students as is found to-day in such subjects as electric railways, power plants and the distribution and transmission of power.

DISCUSSION.

PROF. CHARLES F. SCOTT (Sheffield Scientific School of Yale University): The significant thing in Prof. Clewell's paper on "Illuminating Engineering as a Branch of Technical Instruction" is the fact that the orthodox method of instruction from a text book leading up logically from the mathematical and physical laws of light is supplemented by a great many other methods. The general educational work of the Illuminating Engineering Society is contributed to by half a dozen or more committees, and the education in the technical school is along varied lines which have to do with the engineering principles in the application and use of illumination, as well as the mathematical and physical and chemical laws in accordance with which light is produced and distributed. Illumination is fortunate in having so many relations that it admits of treatment in many ways. Furthermore, illumination is a matter entering into the experience of everyone, so that its importance is apparent to all and an interest naturally arises. Interest is quite easily awakened when we find new facts and laws and new relations with regard to things with which we are already familiar and have assumed that we knew all about. When a simple illustration or explanation or a little analysis shows that conditions which have entered into our own experience are really not satisfactory, but violate some common sense condition which we had never thought of, we are apt to be startled; we realize that our powers of observation and simple reasoning have not been active. In brief, illumination is a fine opportunity for the cultivation of the observing and reasoning powers. Sometimes the highest order of invention consists in accomplishing something which everybody may recognize at once as the obvious and proper thing, although they somehow did not happen to think of it at first.

Prof. Clewell's paper, therefore, indicates new and varied ways of technical instruction, which are of great value as a type of training, as well as a source of information for the engineer. Illumination, the new branch of engineering, is fortunate in being able to give a stimulation to engineering education.

PROF. HAROLD PENDER (University of Pennsylvania): In this paper Mr. Clewell describes the work conducted for two years

in conjunction with Prof. Scott at Yale University in giving work in illumination to undergraduate and graduate students, also the work of the past year at the University of Pennsylvania along these same lines. The object of the paper, apparently, is not to set forth the idea that these courses are looked upon as all that could be desired, but merely to describe what has actually been accomplished at two institutions thus far. The underlying object of the paper has been to invite discussion which would tend to help the author in any future work conducted in the development of this particular line of instruction.

At the University of Pennsylvania the aim in the electrical engineering department is to place each line of work as far as possible in the hands of men fitted by practical experience or special study to make them competent to plan the courses to the best advantage. In this way the instructor is able to concentrate his attention on relatively few subjects and satisfactory results in such specialized courses as telephony, railways, illumination and motor applications have thus been possible. The course in illumination involves a relatively small amount of time in the principles of illumination, supplemented by photometric and illumination experiments in the laboratory. The laboratory is equipped with all types of modern electric illuminants.

Mr. Clewell points out the value of a course in illumination not only to electrical but to non-electrical students. Thus the mechanical engineer from the standpoint of the future works manager should have almost if not as keen an interest in factory lighting as has the electrical engineer in other special lighting fields.

The fact that there is at present only a limited call for men specially trained in the principles and practise of illumination is largely due to a failure on the part of those in responsible charge of shops, factories and large offices to appreciate the importance of good illumination from the standpoint of the efficiency of the worker. The remarkable increase in defective eyesight in the last fifty years is probably due more to poorly designed lighting installations than to lack of light; it is proper distribution rather than brilliancy that is of primary importance. A better understanding of the principles of illumination by all kinds of engineers will in the long run mean not only an improvement in the "public

health," but also an actual saving in dollars and cents to the employer of labor.

MR. WILLIAM J. SERRILL: Prof. Clewell has given us in this paper a very interesting discussion of the educational side of illuminating engineering. In the engineering schools of the country there is to-day noticeable a marked tendency away from specialized courses, and in favor of a thorough instruction in general principles that underlie all engineering. This refers to undergraduate four-year courses. In the practise of law, there are probably as many different branches of work as there are in engineering. In the law schools, the instruction for all students is uniform, and they all get the one degree of doctor of laws. I look forward to the time when a similar situation will exist in engineering schools. The principles underlying engineering in general will be thoroughly taught, and the one degree of doctor of engineering will be given. The graduate will equip himself for specialized work in a post-graduate course, or will do so by his own efforts after leaving college.

The principles underlying illuminating engineering are of such importance that they should undoubtedly be included among those general principles which are taught to undergraduates. The engineering school of the future will undoubtedly be equipped to turn out a finished illuminating engineer as a post-graduate product.

The presentation of the principles and practises of good illumination before students other than those in the engineering departments is desirable, and the popular lectures which Prof. Clewell's committee is preparing, as well as other illustrated lectures on the subject, are undoubtedly an admirable means of spreading the propaganda of better illumination among educated people. The thing is to overcome the natural indifference to the question of illumination, and to awaken an interest in this subject among the students. Especially is it important that students in the architectural schools and those in the medical schools be made aware of the importance of illumination as affecting the great professions of architecture and medicine. In both professions there is great ignorance of the principles of illumination, and the most effective way of improving this condition is to work on the

students in these departments, rather than to attempt to influence the practising architect or physician.

Mr. Norman Macbeth: There seems to be a question in the minds of many when considering the employment of graduates as to the value of a course in illuminating engineering. To my mind this situation is due to a failure to appreciate the value of such a course, or perhaps to the usual conception of what the present illuminating engineer stands for. The so-called and self-styled illuminating engineer, who has been most prominent in the commercial field within the past five or six years, has in many instances been neither an engineer nor a commercial man, and has left a deep impression in many minds as lacking more than he possessed.

There is no disagreement as to the value or usefulness of an electrical engineering course, and graduates find employment in widely diversified fields of electrical apparatus design, manufacture or application. There is no confusion as to where and how the electrical engineer's education may be applied. The electric railway field, telegraph, telephone and wireless, electric trucks, power applications, etc., afford many opportunities. The course for the electrical engineering graduate covers a wide range of electrical applications. So far as the course itself is concerned, however, many of these applications have been merely touched upon, and the final usefulness of the training of the graduate most likely comes through a specialization of some one branch.

And so it will be with the illuminating engineering graduate. There are thousands of opportunities for trained men in the lighting field to-day. The entire lighting field is largely in the hands of mechanics and men quite unfitted so far as training or an appreciation of their responsibilities is concerned. And the results so much desired are largely based on thumb rule and guess to say nothing about indifference.

In the United States alone in 1913 our sales of lighting equipment totaled over $65,000,000 and of central station energy for lighting over $300,000,000 per annum. It may be noted that the central station receipts from lighting are more than twice that from the much talked of and consistently sought power load. Surely a business of $400,000,000 annually—and it is greater than

this if we include gas lighting—a business which is so closely and intimately associated with our lives and with the health and enjoyment of the people, and admittedly so ineffectively handled to-day, presents opportunities for illuminating engineering graduates.

In the applications of lamps, glassware and lighting fixtures, in contracting and construction, there are opportunities for men who know the fundamentals of illuminating engineering and have the common sense to apply their knowledge. A graduate illuminating engineer with a course which is at all comparable with that of the electrical engineer, retaining as much of his course as the average electrical engineering graduate, has vastly greater opportunities for usefulness; and it is this usefulness which in any field commands salaries worth while.

The illuminating engineer has not as yet sold his proposition either to the management of his company or to the general public, but when he does, and that time is not far off, he will readily secure his proportion of the many millions expended in this field.

Mr. P. S. Millar: The New York Section is privileged to have presented before it this paper on the educational phases of illuminating engineering. I am sure that we have been interested in the accounts of the introduction of these two courses in Yale University and the University of Pennsylvania. It seems to me, however, that a great part of the moral of this paper must lie in its application and that to make it most useful it must be placed in the hands of members of faculties of colleges and universities which might utilize it and apply it to their advantage.

It occurs to me that we are about to issue a report of last year's Committee on Education and that it would be an excellent plan to include copies of Mr. Clewell's paper with copies of the report.

With regard to this question of illuminating engineering education it seems to me that there are three points of view, respectively that of the educator, that of the employer and that of the Illuminating Engineering Society. In university education it apparently is the tendency to broaden under-graduate engineering instruction, and to include in a graduate course such special instruction as illuminating engineering. With reference to employees, this year's Committee on Education, under the direction

of Prof. Richtmyer, is planning a canvass to ascertain what demand corporations might have for engineers who graduate from a special course in illuminating engineering, such as is contemplated. If I rightly understand the point of view of the society it is that we are not prepared to urge instruction in illuminating engineering at the present time. We are anxious to do all we can to pave the way for it, and wish to be prepared to supply such information as it is within our power to make available whenever there exists a demand for it. We want, of course, to promote the movement, but at the present time we do not see that the time is ripe to urge any extension of this form of education.

Prof. Clewell's paper, it seems to me, if properly applied in colleges and universities, is going to do much toward assisting in creating this demand which the society wants to meet.

Prof. Arthur J. Rowland (Drexel Institute): Educational work in illuminating engineering is so constantly connected with electrical engineering courses only that I am glad to note the remarks in Prof. Clewell's paper and emphasize the fact that such education has a far wider application. I have been constantly surprised that, though electrical engineering courses invariably contain a course on electric lighting, in connection with which the study of electric lamps themselves and some study of illumination by these lamps at least are taken up, nothing of a corresponding kind exists in mechanical engineering courses. It seems to me that the place to start with training in illuminating engineering is in the regular college physics courses. It is true that the textbooks are not adapted to this, but it is surely time that along with the study of light the terms and nomenclature of illuminating engineering should be introduced. The application of light for illumination should be made at least as much of as the use of lighting appliances to which considerable time is given in our college physics courses.

Taking two hours per week through the senior year of engineering, a really valuable course in illuminating engineering can be given. In the electrical engineering course at Drexel Institute this amount of time has been given for a number of years. In it can be included not only all the fundamental principles of illumin-

ating engineering practise, but a number of problems relating to indoor illumination, including arrangement of lamps and circuits to supply them, as well as a study of the various illuminants available for everyday service. Students seem to enjoy this course very much and take hold of its practical problems with avidity, even when considerable outside time is required of them. It seems to me that the actual photometric and illumination measurements which are to be done must inevitably be carried along as part of the engineering laboratory work. It is impossible to organize or to spare the time for a special course in photometry and illumination measurements.

While I believe in such a course not only for electrical engineers but for others, I have grave doubts as to the real value of such training in comparison with that found in other branches of engineering knowledge. This is because in my experience there is very slight demand indeed for men who have been trained specially in illuminating engineering work. Philadelphia is a rather large town and it is possible to judge the importance of various engineering subjects by the demand for them in evening class work here. For half a dozen years among the college subjects offered in the evening classes, Drexel Institute has offered a course in lighting and illumination. I have personally taught this class, and I think I am well enough known in the Philadelphia Section of the Illuminating Engineering Society to have as good a chance as anyone else to secure a class. A very small class was carried in this subject for two years. We have, however, now decided to abandon the work since we have given up any expectation of finding any demand for such training. There is a much larger demand, for example, for training in telephony, which seems to be a highly specialized line. In fact, those who study telephony must nearly all of them of necessity hold positions with a single telephone company. There are many firms in Philadelphia and many consulting engineers' offices in whose business lighting and illumination plays an important part. Nevertheless there is clearly no interest in and demand for such courses of training here.

PROF. A. A. ATKINSON (Ohio University): The subject of illumination offers not only a very interesting field for scientific

investigation, but also furnishes one of the most useful and delightful forms of study for a great body of students, even those in domestic science and educational courses. It takes rank in the technical field alongside the finest lines of research; in practical every-day importance alongside hygiene, sanitation, etc. Scarcely any other line of thought or investigation touches so many phases of practical life, offers so many opportunities for the cultivation of the artistic and esthetic sense, or is allied with so many other technical professions.

The method of Prof. Scott quoted by the author of the paper should prove an excellent means of arousing an interest in closer and more intelligent observation of illuminating conditions and of cultivating powers of analysis and the formation of correct judgment. I note, however, that most of the student reports quoted by Prof. Clewell ended with the statement of found conditions only. I believe that senior and graduate students should be required to draw conclusions from their observations as to methods of improvement of the conditions found and reported, and even to propose plans showing how they would proceed to make the modifications suggested.

The general course outlined by the author as the result of his experiences in teaching the subject seems to be an excellent mode of procedure. The combination of the observational and descriptive phases, calculations based on specified conditions, and finally actual illumination measurements both in the laboratory and factory should make up a course, when supplemented by lectures given by experts engaged in practical illumination, of great educational value and absorbing interest to every student.

I hope the time will come shortly when the teaching of this very interesting subject will be very general and uniform in the colleges throughout the whole country.

Mr. R. E. Simpson: Graduates of mechanical and electrical engineering departments of our technical schools and colleges are very often in a position in which they are called upon to approve or disapprove the present lighting system, or a new lighting system, in a factory. Much more than the mere saving of a few dollars on the monthly lighting bill is dependent on the decision made. Generally speaking, the increase or decrease in the light-

ing bill should not be the determining factor, for this is of minor importance when the ultimate results are considered. Decrease in spoilage and seconds, increase in production and efficiency of the workmen, and the safety of the employees are of far more importance than the saving in the lighting bill. Referring to the last one of these items, namely, the safety of the workmen, the influence of the lighting installation may be felt in the profit and loss item because of damage claims. Assuming that an engineer, because of his unfamiliarity with illuminating engineering, should decide on a lighting system that will not provide proper illumination for the work, but which will save an average of $25.00 per month compared with the cost of the old system. He then will have saved his company $300.00 per year, provided no one of the workmen is injured because of the inadequate or improper illumination. At the present time I am gathering statistics on illumination and accidents and although the investigation has only recently been started, the average of the figures so far obtained indicates that the cost of one accident would more than offset the saving in the lighting bill for the year. Any additional accidents which might be charged to the lighting conditions simply add so much more to the cost of the illumination. In states having workman's compensation laws the question of accident prevention is a matter of real concern to the factory owner or manager. It is decidedly to his interest to keep informed on every item that enters into accident prevention work. The mechanical or electrical engineering graduate who intends to enter the manufacturing field should therefore have as thorough training in the fundamentals of illuminating engineering as in other subjects, if in him is to be lodged the authority to pass on lighting questions, as well as on other engineering matters.

Prof. W. E. Barrows (University of Maine): I have read Prof. Clewell's paper with much interest and at this time I wish to express my appreciation of the good work which the Committee on Education is doing.

It was my privilege to give the course in illuminating engineering at the Armour Institute of Technology in 1907 when the subject was offered there for the first time, and I have been teaching that subject each year since that time. When I became

associated with the University of Maine, the electrical course was changed somewhat, and the subject of illumination added to those of the curriculum. It was received with interest and has proved a success.

One of the features of the course which has received much attention has been the arrangement of the subject matter of the course so as to secure the greatest amount of interest on the part of the students and, at the same time, cover the subject in a logical order.

While using my book "Light, Photometry and Illumination" as the basis for the course, it has seemed advisable from the standpoint of interest on the part of the class to first take up in a general way the subject of illuminants in their different forms, together with their characteristics and uses. By so doing, the student at once becomes aware of things more general than he had learned in physics and is keen to refer to these illuminants when taking up the fundamentals of luminous radiators, photometry, illumination calculations and interior and exterior lighting.

It has been found valuable to assign a certain lighting installation to each student to study, criticize, redesign and discuss. The reports are then taken up in the class and there discussed. The results have been valuable and interesting. Several of the fraternities have halved their lighting bills, and the dormitories exhibit the recent lighting systems using various devices from a new tin dish to a mirror reflector for the indirect lighting system.

I believe there is an excellent field here in Maine for popular lantern slide lectures not only before student audiences but before commercial and business organizations throughout the state. The vast amount of available water power in this part of the country, with prospects of additional development in the near future, indicate low rates and there must follow a more extensive use of electricity for lighting purposes. Moreover, the practise with regard to lighting equipment is in general not in accord with the times. This should make an excellent field for the illuminating engineer.

Prof. Alan E. Flowers (Ohio State University): Mr. Clewell is to be congratulated for giving an excellent description of

successful courses in illumination. I am strongly inclined to favor placing courses dealing with specialized branches of engineering in the graduate school, as was done with the course in illumination at Yale, but I think that every engineering curriculum should include a general engineering course extending throughout the senior year, which would include a brief treatment of each of the important engineering fields, in such a way as to bring out their interrelations, relative industrial and technical importance and their possible future developments. This course should consist of lectures, correlated reading and problems. Illuminating engineering should find a place in this general course and its treatment should be designed to give every student a grasp of the principles of illumination, some conception of the importance of good illumination and some idea of the magnitude of the technical work being accomplished in this line and what the professional prospects would be for a man entering this field.

Dr. Clayton H. Sharp: The paper by Mr. Clewell is a most useful one, both on account of the information which it brings together and of the practical ideas which it contains. The teaching of illuminating engineering is making its way in our technical schools with certainty, but perhaps not with the rapidity which we should wish for. The reasons for the latter condition may be, beside natural inertia and indisposition of men to take up new things, and the lack of time both on the part of the instructors and the students for treating them, first, that the importance and the many-sidedness of the subject are not entirely appreciated on the part of the instructors, and second that the point of departure and method of attack in teaching the subject have not been indicated in a sufficiently definite and practical way. In both these regards the hints contained in Mr. Clewell's paper should be most helpful. When it is fully realized that illuminating engineering presents a field which touches the every-day life of everyone more intimately than any other branch of engineering, with the exception of heating and ventilating, and when the educational value of a course in illuminating engineering in training the observational faculties, the judgment and the use of common-sense on the part of students, as well as their ability to make precise measurements along lines where only in recent

years it has come to be realized that measurements are both feasible and necessary, the progress of the teaching of this subject should be greatly accelerated. It seems to me that Mr. Clewell's paper should be of very great assistance to the propaganda carried on by the Committee on Education of this society and that a great many copies of it might be used to good advantage for this purpose.

Prof. F. K. Richtmyer (Cornell University): The paper is particularly interesting to me not only because of the excellent material, which is a valuable contribution to the subject, but more important still, from the broader standpoint, because of that for which the paper stands: a pedagogical experiment. We need more experiments of this kind, and less generalization as to the methods to be employed in teaching.

Prof. Clewell has mentioned the keen interest shown by students of illumination. I have found a similar attitude among students whom I have taught. And not until recently, did I realize the reason. Those of you who are familiar with college students, say seniors, know that they have reached a point in their educational career where they like to criticize. When you send a student on such an expedition as Prof. Clewell has described, to investigate conditions of lighting in shops, stores, show windows, etc., he finds so much to criticize that he is perfectly happy. It is not difficult to get his interest. Twenty years from now, when you engineers have standardized lighting practise, so that there are not so many "glaring" examples of poor lighting, you will probably make it more difficult for us teachers to interest our students.

There is one point regarding which I would like Prof. Clewell's opinion: where, in the course of the instruction is the proper place to introduce some of those things which the engineer does not meet in his curriculum? I refer to the close connection between illuminating engineering, and architecture, physiological optics, psychology, art, etc. For example, it is obvious that every illuminating engineer should know something of architecture. Yet how can we make the student appreciate the architectural principles involved when we who teach him have never had a course in architecture ourselves?

Prof. Clewell has mentioned the difficulties encountered in interesting the directors of educational institutions in instruction in illuminating engineering. I think the reason is not so much due to the jealousy with which each professor guards his subject, as to the point brought out by the comments of Mr. Serrill, as read by the chairman. Your practising engineer of to-day, in order to be a real successful engineer, must be more or less of a specialist, and just in so far as he must be a specialist, his education, his fundamental education, must be broad. Our colleges are therefore compelled to cut out a great deal of specialization in the course of instruction and in its place put broadening subjects —a more sure foundation for work which is to follow. In a certain university for example we used to have courses in marine engineering, in railway mechanical engineering, in steam power engineering, in gas power engineering, mechanical engineering and perhaps a half dozen other courses in which the student was supposed to specialize in his senior year. These have been practically all cut down to two or three branches and at the present time there seems to be little room, little tendency, for branching out again by adding a course in illuminating engineering. It is assumed that the young engineer, in the first few years of his practise, will on his college course as a basis, build up a knowledge of his specialty. But there is this difficulty. It seems to me that the course in illuminating engineering is not quite on a par, so far as instruction in mechanical engineering is concerned, with courses in say marine engineering or railway mechanical engineering because there are so many factors—architecture, physiology, psychology, and so on—which the student does not meet in his general course, and which he is, therefore, not familiar with when he comes to his professional practise.

Prof. C. B. LePage (Stevens Institute of Technology): I have followed Prof. Clewell's paper very carefully and believe it to contain many very valuable suggestions for those of us who are teaching illuminating engineering or its related subjects. This paper is certainly a very clear and concise report of some good work which is being actually accomplished. I expect to study it with a great deal of interest and I desire now to thank Prof. Clewell for presenting it at this time.

At Stevens Institute of Technology we have, as yet no connected course in illumination. During the sophomore year we give the students the physics of light, photometry, and illumination by lectures, recitations and laboratory exercises. This work is followed in the senior year, by lectures on the modern light sources and laboratory work in distribution measurements, all given as part of the electrical engineering laboratory course. All our graduates, as you know, receive the degree of mechanical engineer.

Prof. C. E. Clewell (In reply): It has been very interesting to me to hear the various views brought out in this discussion, and in particular to hear from Prof. Scott and Prof. Pender. Both of these men stand for new electrical engineering departments in two of the largest universities in the country, and it is significant that they have manifested, as their discussions show, a decided interest in illumination as a branch of technical instruction.

Mr. Serrill's suggestion that the coming engineering curriculum will probably lead to a degree in engineering is certainly somewhat of a departure from the ordinary views of college education as manifested by present specialized courses. However, if one keeps pace with the times, he cannot fail to see that engineering work in the schools is coming more and more to be looked upon as a training in the broad fundamentals of engineering, rather than to separate the courses into electrical, mechanical or civil engineering as the case may be. These different courses will doubtless continue under the jurisdiction of given departments, but at the same time the concentration on fundamentals of engineering in its broadest sense can receive due attention.

Prof. Rowland's statement that in his evening classes he has found no demand for illumination work must be looked upon, I believe, from the standpoint of the call for particular lines of work which normally follows the demand for men trained in these directions. As Mr. Macbeth has pointed out, there is a probability that in the future there will be a great demand for men trained in this field, and when such a time arrives, the demand for illumination courses will follow as a logical result.

Regarding Prof. Atkinson's suggestion that in reports like those mentioned in the paper conclusions should always be included by the student, it should have been stated that in these particular reports conclusions were added although they formed no part of the paper.

Prof. Barrows calls attention to the importance of proper arrangement of work in engineering courses so as to secure the best results. This feature coincides exactly with my own views as outlined in the paper.

I want to express my appreciation to Prof. Richtmyer for his comments on the paper and in particular for the fact that he classes the work back of the paper as an educational experiment. This is the manner in which the work has been looked upon during the past three years and his view that it is both stimulating and healthful in educational work to have such experiments from time to time seems most appropriate. Answering Prof. Richtmyer's question as to the proper place for the introduction of the kinds of things which do not normally find their way into the engineering curriculum, such as architecture and psychology for example, the student branches of the national engineering societies might well be used as an opportunity for lectures from men in these other lines of educational activity.

It was not intended in the introductory remarks of the paper to give the idea that the jealousies of college professors are responsible for the difficulty in finding room for new lines of instruction work. As pointed out by Prof. Richtmyer, college courses are already too crowded in many cases to warrant more than the broad fundamental items which are required by the future specialist. There must then be a good and sufficient reason when one or another existing courses are replaced by something which is new and different.

In conclusion, the approval which Mr. Millar has placed on the efforts which have resulted in this paper is gratifying and if the material should be considered by the Committee on Education of sufficient interest to be sent out as a supplement to the annual report of that committee, this may be the means for hearing from others who receive the paper and who may be in a position to offer new and improved ways for conducting this particular line of educational work.

THE OPTICAL PROPERTIES OF DIFFUSING MEDIA, I.*

Synopsis: This report is the first of a series dealing with the classification of diffusion and the general properties of diffusing materials. The reflection and transmission of light is either specular, semi-specular, semi-diffuse or diffuse. These four classes are defined and illustrated. Definitions of turbidity, gloss, glare, density and other terms are suggested. The various kinds of data obtainable and required in practise are outlined. The theory of contrast is given, and finally the physical theory of scatter.

TYPES OF DIFFUSION.

Light reflected from or transmitted through various materials is scattered in varying degree. Part of the light may be highly diffused and the remainder reflected specularly, as in a mirror, or all the light may be more or less scattered. Further, the diffusing properties of many materials vary markedly with the quality of the light. Colored objects with surface polish, specularly reflect all wave-lengths, but the ratio of diffusely to specularly reflected light is much greater for the color exhibited. Thin opal transmits a red image of a lamp filament, but viewed through opal and a blue filter no specular image of the filament is seen. It is convenient in treating diffusion to distinguish four quite distinct glasses.

1. *Specular Reflection and Transmission.*—Specular reflection is exhibited by plane polished surfaces not scratched, dirty, wavy, nor, if not opaque, reflecting diffusely from within the surface. Bodies transmit specularly if their surfaces are plane and clean and if they contain no imbedded diffusing bodies or particles. Scratches, dirt or undulations on surfaces or imbedded particles in a material produce diffusion in general *only* if their least dimension be large compared with half the length of a light wave; *i. e.*, a quarter of a thousandth of a millimeter or a hundred

* Report No. 2 of the I. E. S. Committee on Glare, submitted in March, 1915.

thousandth of an inch. Smaller irregularities may absorb but never scatter light. Larger irregularities produce diffusion of either the second or third type.

The brightness of a specularly reflected image is equal to that of the source of light, viewed on a line through the point of incidence, times the reflecting power of the surface. Reflecting powers range from about 0.02 for water to 0.064 for glass, and from 0.16 to 0.98 for metals. A specularly transmitted beam suffers loss by reflection from surfaces and from internal absorption. Transmission, $T = (1\text{-}R)^2 (1\text{-}A) = T_1 T_2$ say, the quantity -log T_2 or -log (1-A) is proportional to thickness.

2. *Partly Specular Diffusion.*—Any reflection or transmission of light in which a distinct image of the source may be seen is classed as partly specular. A dusty mirror or a sheet of glass over-

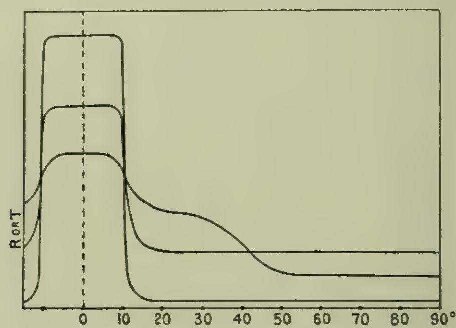


Fig. 1.—Types of partly specular reflection and transmission.

lying paper exhibits typical semi-diffuse reflection. Corresponding examples of transmission are given by atmospheric haze and by glass or ice filled with bubbles. Of the original incident beam a fraction is absorbed, another specularly reflected or transmitted, and a third scattered in all directions in various proportions.

In Fig. 1 are plotted distribution curves typical of reflected or transmitted beams of light in which some specular remains. The projecting knobs represent the residual specular light, their width being the angular width of the source and their heights proportional to the coefficient of specular reflection. Their area relative to the total area is the fraction of the reflected or transmitted

beam that is specular. The various types of semi-specular diffusion differ in ratio of diffuse to specular light and in distribution of diffuse light. Each curve is from actual data. In colored materials these curves vary greatly with the quality of the illumination.

3. *Nearly Diffuse.*—Reflection and transmission are classed as nearly diffuse when the specular image is completely broken up, yet the diffusion is far from complete. The reflection from calendered papers and other wavy surfaces and the transmission through ribbed and chipped glass and oiled paper are of this class. Typical distributions are illustrated in Fig. 2.

Diffusion varies from high and nearly uniform to that which is nearly all confined to very near the specular angle.

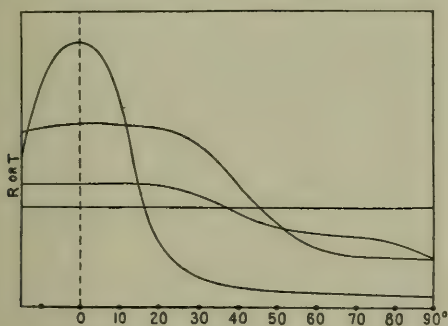


Fig. 2.—Types of semi-diffused reflection and transmission.

With this class of diffusion any quantitative definition of *glossiness* or of *glare* must be arbitrary for there is no truly specular reflected or transmitted light. It might be agreed, for example, to take the ratio of the light within 10° of the specular angle to the total in certain cases, say focusing screens. This would doubtless be advantageous in comparing materials of the same class, but definitions rational and useful for *all* classes of materials seem out of the question.

Probably the most scientific analysis and specification of non-specular beams would be to treat them as aggregates of miniature specular or semi-specular beams. An analysis of the beam would thus give by deduction the surface of internal structure of the surface producing it. For a wavy surface we should thus derive

a mean amplitude and period; for a surface composed of minute planes we should be led to a probability law of angular distribution. However interesting such analyses, they would be of little practical value compared with the distribution curve itself. An outline of the theory of the action of such aggregates is given at the end of this report.

Both reflecting power and coefficient of transmission vary with both the angle of illumination and angle of reflection or transmission. *Mean* reflecting power is the ratio of total reflected to total incident light for any given (say perpendicular) illumination. *Absolute* reflecting power is the ratio of reflected to incident light when the incident light is perfectly diffuse. The mean and absolute coefficients of transmission are similarly defined.

Certain arbitrarily defined quantities are useful in comparing materials of the same class. With perpendicular illumination, brightness is measured at angles of 0°, 45° (reflected), 135° and 180° (transmitted), B45° : B0° is a measure of *entrant scatter,* B135 : B180 of *exit scatter* (v. infra).

4. *Diffuse Reflection and Transmission.*—When a surface that is uniformly illuminated appears equally bright viewed at all angles of reflection or transmission, the reflection or transmission is perfectly diffuse. Blotting paper, felt, snow and other masses of fine crystals exhibit nearly perfect diffuse reflection. Good opal glass and a few other materials give nearly perfectly diffuse transmission.

The reflecting powers of some diffusely reflecting surfaces is independent of the angle of incidence, in others not. The difference appears to be due to the shadows cast by minute pits or projecting particles. When these are present, oblique illumination is accompanied by a decreased brightness on the side away from that on which the surface is illuminated. Surfaces of crystalline powders formed by pressing with a plate of glass are quite free from this effect and also from specular reflection.

PROPERTIES OF MATERIALS.

Granular Glare.—Direct sunlight reflected from the wavy surface of water or transmitted through ribbed glass gives typical granular glare. The brilliant points or lines are such as reflect or transmit specularly while the intervening spaces are of much

lower brightness and give highly diffused light. Intrinsic brilliancies and contrasts are met with as excessive as those met with in filament lamps without diffusing screens and just as objectionable.

The size of grain that is tolerable depends upon the degree of contrast. Halftone dots with a contrast of but 20 : 1 are quite unobjectionable but brilliant points of similar angular size would be intolerable. Excessive contrasts are tolerable only when the angular size of grain is below the resolving power of the eye or about half a minute of arc in angle.

Measurements may be made upon either average brightness or brightness of detail and the results specified either as a glare, a contrast or a brightness distribution. An image of the surface is either magnified or diffused if required for measurement.

Thickness of Diffusing Layer.—Diffuse reflecting power increases steadily to a fixed maximum value with increasing thickness of diffusing medium. Diffuse transmission increases rapidly to a maximum then decreases to zero for thick layers.

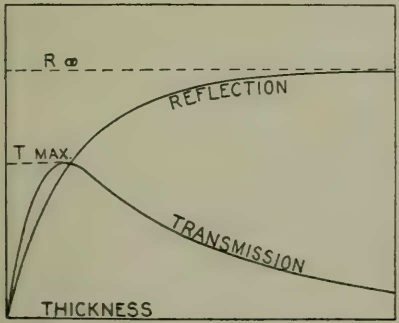


Fig. 3.—Effect of thickness on diffusion.

Fig. 3 indicates graphically the variation with thickness in a typical case. Similar curves have been obtained on thin wedges of opal glass illuminated perpendicularly and viewed at angles of 45 and 135° from the normal.

Reflecting power follows closely the simple exponential law: $R = R_\infty(1 - e^{-kt})$ constant k being a measure of the *turbidity* of the material and R_∞ the maximum reflecting power attained with increasing thickness of material. The diffuse transmission

also appears to follow an exponential law, but not so simple a one. In the theory of diffusion given below these exponential laws are deduced from simple assumptions as to the nature of scatter.

Suppose a light flux I_o is incident on the first surface. $I_o R$ is reflected and $I_o - I_o R$ or $I_o (1 - R)$ enters the surface. Of this, $I = TI_o (1 - R)$ is transmitted to the back surface. The transmission T is computed from $I:I_o$ and R, all three of which are measured. $T = I/I_o (1 - R)$

$$D = -\log T = \log O, \ O = 1/T.$$

Opacity O is the reciprocal of percentage transmission. Log O = -log T is D the *density*, a quantity proportional to thickness. Specific density is the density divided by the thickness in mm. Measurements on opal glass, piles of paper, blocks of magnesium carbonate, etc., show that the density law holds well.

The amount that print on the back of a sheet of paper shows through (contrast ratio) is simply related to the above constants. The light returned to the front surface is $T^2R(1 - R)$ where the sheet is backed by a similar sheet, $T^2R_i (1 - R)$ where backed by ink of reflecting power R_i. The brightness of the front surface is proportional to the initial reflecting power plus this returned light. Back contrast C_b is then

$$C_b = \frac{R + T^2R\ (1 - R)}{R + T^2R_i\ (1 - R)}.$$

If R is large and R_i is small, as in ordinary cases, $C_b = 1 + T^2 (1 - R)$ to a very close approximation.

Another quantity of value in describing the diffusion of special materials is the *diffusion efficiency*, the relative brightness at some assigned angle to the brightness viewed perpendicularly. For example, with projection screens intended to be viewed at angles up to 30° from the normal, relative brightness at 30 and 0° is a proper measure of diffusion efficiency. With focusing screens B170 : B180 may be used as a criterion of efficiency.

Angle of Illumination.—The ratio of the diffuse to the specular brightness of a surface varies with the solid angle subtended by the illuminant. That angle may in practise be anything from almost a point (sun or Nernst lamp filament) to a hemisphere like an overcast sky. The simple problems may be treated as follows:

Specular brightness B_s is equal to the brightness of the source B_o times the coefficient of specular reflection (R_s) or transmission (T_s) as the case may be. *Diffuse* brightness B_d is such that $\pi B_d = B_o R_d \omega$ for not too large solid angle ω (= area/dist.^{2}) of source and nearly perpendicular illumination. Both B_d and B_o are in light units per unit area, say in lumens per square cm. $B_o \omega = B_o \times$ Area/(dist.)^2, is the *illumination* and the factor π converts this into brightness. For illumination at a considerable angle, a correction for oblique incidence must be applied (by integration of the cosine of the angle of illumination) amounting to a factor of ½ for illumination from a complete hemisphere. In Fig. 4 is plotted the ratio of diffuse to specular brightness with increasing solid angle of the source of illumination.

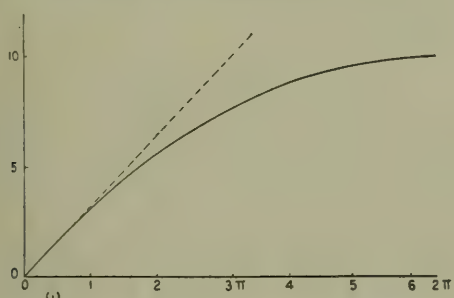


Fig. 4.—Ratio of diffuse to specular brightness.

For a source of limited extent and nearly normal illumination, therefore, the ratio of specular to diffuse brightness is

$$G = \frac{B_s}{B_d} = \frac{R_s}{R_d}\,\frac{\pi}{\omega}.$$

This ratio of total to diffuse brightness is a logical definition of *spot glare*. Since it depends upon the illumination as well as the material, it is not a specific property of a surface or material, but of its *appearance* under stated conditions. Glare cannot be expressed in terms of reflecting or transmitting power alone. For a source of small solid angle such as the sun, an arc or a lamp filament, glare may have very large values unless specular reflecting power be very small.

The glare from large angle illumination must be treated by elements, since both reflecting powers as well as the illumination

varies with angle of incidence. It is always small and of little practical importance.

Contrast is relative total brightness. Call this C, then

$$C = \frac{B_d + B_s}{B'_d + B'_s},$$

B_d and B_s being diffuse and specular brightness of one part of the surface and B'_d and B'_s of neighboring portions whose contrast with the first is to be specified. For rather small illuminants we may put as above $B_s = B_o R_s$ and $\pi B_d = B_o R_d \omega$, hence

$$C = \frac{\omega R_d + \pi R_s}{\omega R'_d + \pi R'_s}.$$

For ordinary glossy print paper and ink R_d is about 0.6 for the paper and 0.04 for the ink. R_s is about 0.02 for the paper and 0.01 for the ink. Hence

$$C = \frac{0.6\omega + 0.02\pi}{0.04\omega + 0.01\pi}.$$

For a small or distinct illuminant ω is nearly zero and $C = 2$. For lighting from a single window, ω is about unity and $C = 9.4$. For a hemispherical illuminant such as the open sky $C = 6.7$. In other words, with direct lighting from a bare lamp the ink may appear half as bright as the paper but with open sky illumination, the paper is nearly seven times as bright as the ink. In extreme cases of glossy ink or paint on a dark matt ground, the print may appear even twenty times as bright as the background.

THEORY OF DIFFUSION.

Certain cases of mixed specular and diffuse reflection and transmission yield to theoretical treatment by which certain properties may be deduced from known data or insight be gained into the mechanism of diffusion.

Specular Surfaces.—Metals reflect high (60 to 98 per cent.) and absorb light very strongly except in very thin layers. The non-metals such as glass, varnish, water crystals of salts and the like, reflect weakly (3 to 5 per cent.) but transmit, if transparent, practically all the light incident except that lost by reflection. Between these two classes of materials there is a wide gap in which only a few solid dyes have intermediate properties. The reflecting power of a metal may be expressed in terms of its refractive index, its absorptive index and the angle of in-

cidence. The reflecting power of a non-metal depends upon refractive index and angle of incidence. The laws of reflection and refraction may be found in any text of theoretical optics such as Wood or Preston. The essential characteristics are those noted above and that the reflecting powers of metals *decrease* while those of non-metals *increase* with increasing angle of incidence. The cases of silver and glass are typical.

	Angle of incidence					
	0	10	20	40	60	80
Silver R =	0.98	0.75	0.70	0.70	0.70	0.70
Glass 1.5 R =	0.04	0.04	0.04	0.045	0.085	0.20

Reflection from an interface between non-metals depends upon the relative refractive indices of the two media (say varnish and glass) and at the same angle is equal on the two sides. Between a metal and non-metal (silver on glass, say) the laws of reflection are not yet fully developed but the reflection is in amount much as though the non-metal were not present.

The reflection from a rough surface such as a powder, a mass of crystals or a scratched surface is simply an aggregate of reflections from the small elementary faces according to the laws for large plane surfaces, except when the elementary faces are small compared with the length of a light wave. In the latter case the reflected waves tend to fuse together as though reflected from the general level.

Partly Specular Diffusion.—In case part of the incident light is specularly reflected or transmitted, the remainder may be highly or but slightly diffused. The theoretical treatment of this case is that of the purely specular reflection or transmission together with that of complete or partial diffusion given below. It may be noted, however, that actual distribution curves always show *some* shading off from specular to diffuse. This behavior is hardly to be expected in the case of a dusty mirror, a hazy atmosphere or of a glass containing bubbles.

Partly specular diffusion is of little if any use as such, but is made use of in studying the atmosphere and the chemical formation of slight suspended precipitates. The minimum perceptible diffusion is extremely small if sufficiently powerful illumination is available. The brightness of the diffused light is proportional

both to the size and to the number per unit volume of particles in suspension.

Pure and Partial Diffusion.—Diffusion is due ultimately to either small spherical surfaces, small plane surfaces, spherical bubbles, wavy surfaces or small opaque particles of indifferent form and orientation. Consider first the problem of the gradual scatter of light in entering a diffusing medium. At any plane element of the medium of thickness dx let

S = flux density of specular light in the direction of x
A = flux density of diffused light in the direction of x
B = flux density of diffused light backward against x
a = total area of grains in unit area of elementary plane
r = percentage of incident light reflected by each grain in all directions.

Then, if the thickness dx of an element is of the same order as the mean diameter of grains

$$dS/dx = -\kappa s - as \qquad (\kappa = \text{absorptive index})$$
$$dA/dx = \tfrac{1}{2}\,arS - \tfrac{1}{2}\,arA + \tfrac{1}{2}\,arB$$
$$dB/dx = -\tfrac{1}{2}\,arS + \tfrac{1}{2}\,arB - \tfrac{1}{2}\,arA.$$

These equations readily give

$$S = S_o\,e^{-mx}$$
$$2A = -(1 + R)\,RS_o\,e^{-mx} - mRC_1x + C_1 + C_2$$
$$2B = +(1 - R)\,RS_o\,e^{-mx} - mRC_1x - C_1 + C_2$$

R being an abbreviation for ar/m ($m = s + \kappa$) and C_1 and C_2 being integration constants. The specular component falls off according to the simple exponential law. The integration constants are readily determined since for $x = o$, $A = o$ and for $x = t$, the total thickness, $B = o$.

Diffuse reflecting power (total) is then given by the ratio of the back emergent light B to the incident light S_o for $X = o$ or

$$\frac{B}{S_o} = R\,\frac{mRt + (1 - R)\,(1 - e^{-mt})}{2 + mRt}.$$

The reflecting power increases according to an exponential law from o up to a maximum value $B/S_o = R = ar/m$ ($= r$ if $\kappa = o$).

Diffuse transmission, given by A/S_o for $X = t$, is a more complicated exponential which is equal to zero both for $t = o$ and for $t = \infty$ and has a maximum value for an intermediate thick-

ness such that the specular transmission ratio is reduced to about 0.1.

Of the light incident on a single particle approximately half the reflected light is reflected at angles greater than 90° from the direction of incidence, hence in a thin layer diffuse reflection and transmission are nearly *equal.* The calculations are not difficult in the case of a reflecting opaque sphere such as a mercury globule, an imbedded bubble or a tiny crystal or opaque particle, but are too long to reproduce here. To mention but one instance: the light reflected at an angle of 90° from a polished sphere is incident on a ring $R/\sqrt{2}$ in diameter and the projected area reflecting light lies half within and half without this ring.

The *distribution* of the light reflected or transmitted by a thin layer is to a first approximation uniform within the hemisphere provided the scattering particles have either (a) spherical symmetry or (b) indifferent orientation. A great many quantitative investigations show this. For example, when a liquid containing suspended particles is illuminated by a rectangular beam, the brightness of the path of the beam is closely proportional to the reciprocal cosine of the angle of view; that is, to the number of particles in the line of vision independently of the angle of reflection from their surfaces.

When a diffusing layer consists of minute planes not indifferently oriented, the distribution of the reflected and transmitted light depends upon the law of orientation of the surfaces. Let p be the fraction of the surface covered by reflecting planes inclined to the perpendicular at angles lying between a and $a + da$. Then p will be the fraction of the light reflected at angles lying between $2a$ and $2\ (a + da)$. This function, times the reflecting power of the surface at that angle, will be the distribution of reflected light. In other words the light distribution $L(a) = R\left(\frac{a}{2}\right) \times p\left(\frac{a}{2}\right)$, reflecting power times angular distribution but doubled in angle.

The transmitted light is distributed in accordance with the law of refraction. The deviation d in passing through a thin wedge

of angle a is $d = a\ (n - l)$ where n is the refractive index of the material. Hence for shallow angles

$$L\ (a) = (l - R)\left(\frac{a}{2}\right) \times p\left(a + \frac{d}{n - l}\right).$$

This law applies to the transmission of ribbed, ground or frosted glass or glass with any kind of wavy surface. Good focusing glass shows, under a microscope, shallow spherical depressions acting like weak negative lenses. Such glasses scatter transmitted light nearly uniformly over an angle of only a few degrees.

In this report certain terms relating to illumination have been used that have not yet been officially sanctioned by the society. These are tabulated below together with brief definitions of each indicating the senses in which each has been used.

Partly specular diffusion: partly diffuse reflection or transmission in which some pure specular remains.

Nearly diffuse reflection or transmission: that in which no pure specular remains but in which diffusion is incomplete.

Reflecting power at any angle: brightness relative to that of a perfectly diffusing surface reflecting 100 per cent.

Total reflecting power: ratio of total incident to total reflected light.

Mean reflecting power: mean of angular reflecting powers with normal illumination.

Transmission; angular, mean, total: analogous to reflecting powers.

Entrant scatter: brightness at 45° / brightness at 0°.

Exit scatter: brightness at 135° / brightness at 180°.

Diffusion efficiency: brightness at maximum effective angle / B0° or B180°.

Turbidity: constant of exponential reflecting power.

Opacity: reciprocal of transmission.

Specific density: -log opacity / thickness.

Gloss: ratio of total to diffuse brightness source 0.01 steradian.

Contrast: relative total brightness.

The terms partly specular and nearly diffuse are used only because none more fitting have been suggested and are not recom-

mended by this committee. The definitions of all the terms, particularly of turbidity and glare, are to be considered merely tentative. For precise definitions of glare and its sub-classes see our general report.

For nearly all of the new matter in this report the chairman alone is responsible, the other members of the committee having read the report but not having considered it in sufficient detail to assume full responsibility for it.

The following report is to cover the practical problems of measuring mixed specular and diffuse reflection and transmission and of specifying the distribution of diffused light.

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THE OPTICAL PROPERTIES OF DIFFUSING MEDIA, II.*

Synopsis: This report deals with the methods of measurement and the geometrical theory of diffusion. It follows a report under the same title dealing with the general properties, nomenclature and physical theory of diffusion media. The following reports are to give the results of extended investigations of various classes of diffusing media by various methods. The numerous methods discussed include laboratory methods of investigation and practical methods for quickly determining important constants, methods for measuring either specular or diffuse reflection or transmission separately, in the presence of the other or of measuring the two combined. The geometry of distribution photometry involved in deducing the required data and constants from observed data is outlined.

The investigation of the optical properties of diffusing media requires means for determining (*a*) the *distribution* of the reflected and transmitted light with any desired illumination (*b*) the *total amounts* of light reflected, transmitted and absorbed and (*c*) the *relative* amounts specularly and diffusely reflected, transmitted and absorbed.

THE DETERMINATION OF DISTRIBUTION.

There is but one general method for determining the angular distribution of the light reflected from or transmitted through the medium studied and that is to mount the specimen at the axis of some form of spectrometer, then determine its brightness with a brightness photometer attached to the observing arm.

Spectrometer.—The crudest form of spectrometer will serve since the sole requirements are a definite axis of rotation and a coarsely divided circle reading only to single degrees of angle. Projection screens are often investigated *in situ* with only a board, a nail and a tape line to direct the photometer and determine angles of reflection.

The Brightness Photometer.—The brightness of the material is best determined with some brightness photometer through which the surface studied is viewed directly. If an illuminometer be used, that surface must be limited to a definite area and the illumination from this on the test screen of the illuminometer at a convenient distance is very faint. A brightness photometer

* Report No. 3 of the I. E. S. Committee on Glare, submitted in March, 1915.

is preferable; when this is used, it should be light, compact and of high precision.

Two forms of these have found favor and others might doubtless be devised. No entirely suitable brightness photometer is on the market. The Beck "Lumeter" is perhaps the best and this requires modification to free it from serious systematic error. The comparison screen is in the photometer box while the surface whose brightness is to be measured is viewed through a hole in the comparison screen. The eye cannot accommodate to the near comparison screen and the distant surface simultaneously, and lack of perfect accommodation seriously affects the brightness of retinal image and hence the reading of the instrument. This failure to provide for equal accommodation is by the way a very common and very serious defect in brightness photometers. The remedy is simply to throw an image of the distant surface into the plane of the comparison screen with a telescope objective or simple lens.

Another suitable brightness photometer is a simple reading telescope with comparison strip or spot fixed in the focus of the ocular and illuminated from the side. Several forms of illumination and illumination control have been used. The use of a miniature lamp filament for comparison strip is objectionable in that it requires the use of a monochromatic filter for precise work.

The Illumination.—The distribution curve obtained for any surface depends of course upon the position of the illuminant and the solid angle which it subtends and it is necessary to use some definite known angular size and position of illuminant. Those most useful are (*a*) nearly parallel light from an appproximately point source such as a Nernst filament or a beam collimated with slit and lens and (*b*) a uniformly illuminated plane area such as a plate of opal glass in front of a frosted lamp. If 11.3 cm. in diameter, or 10 cm. square, it subtends at 1 meter 0.01 steradian.

If the point source or collimated illuminant be used, specular brightness rises to a high value. The illumination is checked by observing the brightness of a magnesium block or other diffusing surface of known reflecting power. When the plane source is used, determinations are in terms of relative brightness of the

illuminant and surface studied. Both forms of source are about equally useful. The collimated beam appears to have no advantage over the point or line source direct, and gives the same distribution curve. The rectangular plane source is to be preferred to the circular since the data obtained with it are more easily reduced.

Fluctuation in the illuminant is, of course, a serious source of error unless counterbalanced by a similar variation in the comparison source. This is easily done if both are electric lamps by putting both on the same circuit. Differences in characteristic curves of the two lamps, control rheostats and the like do not cause serious differential variations if the line voltage varies not over 2 per cent.

The Data.—The brightness of a surface viewed from any angle is a measure of the light per unit solid angle per unit projected area of surface leaving that surface in that direction. With the gonio photometer (angular photometer) above discussed and a given illumination, brightness is measured at each angle in a plane through the incident beam and perpendicular to the surface. Brightness as a function of angle, B (α) say, is then plotted. Light emitted per unit area is then proportional to B (α) $\cos\alpha$, the angle being measured from the perpendicular to the surface. If at the point observed, the illumination is all nearly normal to the surface this emitted light may readily be integrated by zonal elements, the ratio of the total light emitted to the light incident being the mean reflecting or transmitting power. The geometry of this process is discussed toward the end of this report.

INTEGRATING INSTRUMENTS AND METHODS.

While the distribution curves of reflected and transmitted light give all the data required, their determination requires a skilled observer, laboratory instruments and considerable time. When only integrated reflecting power, absorption or transmission are required, much simpler instruments and methods are available.

Anyone or all of these classes of data may be required (1) *mean* reflecting power or transmission; *i. e.*, the light emitted through a hemisphere relative to the light incident in a normal

pencil; (2) illumination hemispherical, observing light a pencil; and (3) both illumination and observation hemispherical (*total* reflecting power or transmission).

Transmission.—Either mean or total transmission may be determined by several different methods. By far the most convenient is to use the König-Martens polarization photometer, really a brightness comparator. It has an excellent field with no apparent dividing line. The error in scale zero is determined by setting in both first and fourth or second and third quadrants. Possible errors due to plane polarization in the light are eliminated by reading with the instrument direct and reversed. When desirable to set on an actual image of the object viewed, it may be provided with a pair of the small lenses used as objectives on a low power binocular microscope.

Uniform diffuse illumination is secured by placing a plate of solid opal glass ground on both sides, over the end of a white paper cylinder within which is an ordinary tungsten lamp. The sample whose transmission is desired is placed over half the field. With this arrangement the readings of the instrument give *mean* percentage transmissions. If *total* transmission is desired, another diffusing medium such as flashed opal glass is placed over both sample and comparison field. Mean and total transmission will be the same when the material is highly diffusing.

Less precise determinations may be made with any brightness instrument such as the "Lumeter" for example. A highly diffused uniform illumination is provided as above, and the sample placed over part of the field. The relative brightness of the covered and uncovered parts of the field give at once the transmission of the sample.

To use an ordinary bench photometer to measure diffuse transmission it is necessary to provide a highly diffused very bright area at one end and limit it to a definite small area. After measuring its apparent candlepower, the sample is placed over it in close contact with it (to avoid side light) and the candlepower again measured. Great care must be exercised in avoiding stray reflected light.

Transmission with illumination by a direct pencil is of importance in diffusing lamp globes and shades and a few other mate-

rials. This may readily be determined by illuminating the specimen with a known flux and determining its brightness on the rear side in the desired direction. If the integrated light emitted in all directions be desired, then a highly diffusing sheet of known transmission is interposed close behind the specimen.

Purely specular transmission may be measured with practically any sort of photometer or spectrophotometer and any source by simply interposing the specimen between source and photometer. Large errors due to refraction are the rule unless the specimen is very thin and plane. If the specimen is very thick, good results can be obtained only by having end faces very plane and by using only very parallel light.

Reflection.—The total and mean reflecting power of surfaces are much less readily determined than transmissions on account of the difficulty in avoiding shadows. The only instrument of general usefulness available for the purpose is the ring reflectometer described on page 413 of the 1912 (vol. VII) TRANSACTIONS of the Illuminating Engineering Society. This instrument measures the relative brightness of two parallel planes, one of which is the specimen surface and the other a diffuse illuminator. The planes are limited by a reflecting ring serving to return the light which would otherwise escape at the edges. The instrument gives mean reflecting power directly except when the reflecting power is either very high or very low and at the same time highly specular. The reading head is a modified form of the König-Martens brightness comparator mentioned above. Reading the head in direct and reversed positions gives data for determining the percentage of light specularly reflected and for correcting for polarization. By a slight modification, this instrument may be used on wall coverings in position.

To measure total reflecting power, perfectly diffuse illumination and observed light integrated over 180° are required. A small receiving disk is mounted half way between the two planes at the center of the ring and the photometer sighted on the two sides of this by means of two small reflecting prisms.

Purely specular reflecting power is determined with a brightness photometer and an extended plane source. The reflecting power of a mirror is the ratio of the brightness of the image to

that of the source at any desired angle of incidence. The specular component in partly specular reflection may be determined by the same method, the source being made either so small or distant or weak as to give only negligible diffuse brightness or else diffuse brightness is measured just off the specular angle and allowed for.

Purely diffuse reflecting power may be determined by determining the brightness under a given illumination. The reflecting power is π times the brightness (in candles per square foot, say) divided by the illumination in foot-candles. This method is not so precise as that in which the brightness comparator is used.

SELECTIVE INSTRUMENTS AND METHODS.

Specular and diffuse reflection and transmission may in most cases be determined separately with sufficient precision for practical purposes without recourse to the more laborious determination of distribution curves. The three classes of partial diffusion of importance require different treatment. These are (*a*) a mixture of pure specular with pure or nearly pure diffuse light, (*b*) a very slight scatter such as is caused by dust suspensions and very light precipitates from a solution and (*c*) diffusion departing widely both from the purely specular and diffuse types.

Separable Mixtures.—In separating specular from diffuse light, one may either measure diffuse and total, specular and total or specular and diffuse separately. With a good brightness photometer any of the three methods may be used. With an illumination of known brightness and solid angle, the specimen is placed at a known distance and angle, then its brightness measured at the angle of specular reflection or transmission and at some neighboring angle, arbitrarily chosen according to the class of the material and the purity of the diffusion. Such materials as glossy paper, polished woods and opal glasses are readily studied by these methods.

Another good practical method depends upon the fact that light specularly reflected at a certain angle (about 60°) is nearly completely plane polarized. Hence if a surface be illuminated and viewed through a nicol prism at this angle, if the nicol be properly oriented, the specular light may be eliminated. The

phenomenon is very striking in the case of materials like polished furniture and glossy paper. Ingersoll[1] has designed a practical instrument for measuring glare based on this polarization phenomenon. The specimen is placed on the bottom of a box and illuminated at the proper angle by an opal window at one end. It is viewed through a polarizing ocular at the other end. With this instrument either relative diffuse and total brightness or relative specular and diffuse reflecting power may be determined.

Ingersoll's instrument or some modification of it promises to be useful for practical purposes when properly used. It should be noted, however, that (*a*) it gives a *minimum* value of the specular reflection, if a surface is quite wavy or rough a crossed nicol does not cut out all the specular light; (*b*) it does not apply to *metallic* surfaces, these not reflecting plane polarized light, and (*c*) it is committed to a particular angular illumination; namely, that of the window supplied. Since the ratio of specular to total brightness varies with the solid angle of illumination, different sizes of window will give different values of gloss.

In using the ring reflectometer (see above) the readings with the instrument in direct and reversed position differ by double the mean percentage polarization, hence give a measure of percentage specular reflection. This method gives fair results in practise. Another method is to use the ring reflectometer to determine total reflecting power and some other instrument such as the modified Bechstein[2] to determine diffuse alone.

An ordinary bench photometer with a Lummer-Brodhun head may be used to determine diffuse reflecting power at perpendicular incidence of certain materials[3] such as paints and papers. The photometer screen is replaced by a double one, half of which is of the ordinary material, and the other half is faced with the material to be investigated.

Slight Turbidity.—The amount of light scattered by atmospheric haze, photographic negatives, light chemical precipitates and other similar agents is proportional to the size, number and reflecting power of the reflecting particles and to the intensity of illumination. The brightness of a slightly scattered beam is

[1] *Electrical World*, March 21, 1914.
[2] TRANS. I. E. S., Vol. IX, p. 611, 1914.
[3] Louis Bell, *Electrical World*, Jan., 1915.

determined by some form of brightness photometer or comparator. Precision, of course, depends primarily upon the intensity and constancy of the illumination and the thickness of the observing path. Direct sunlight is, of course, by far the best illumination. In photographic negatives the scatter is so great that it may be determined by measuring specular and total transmission by ordinary methods.

P. V. Wells of the Bureau of Standards[4] has designed a "turbidimeter" for measuring slight diffusion in solids, liquids and gases. Mecklenberg and Valentiner[5] have designed a somewhat similar but very elaborate instrument primarily for liquids. Both instruments determine the relative intensity of direct and scattered light. T. W. Richards has designed a turbidity comparator which he calls a "nephelometer." The liquids are contained in a pair of silvered test tubes illuminated from the side through slits in the silver. Atmospheric scatter has been studied by Diercks,[6] the photometer being pointed at various angles from the limb of the sun. He found a drop to nearly pure diffusion at about 4° from the sun, the brightness at that point being on moderately hazy days, about one ten-thousandth that of that solar disk.

Inseparable Mixtures.—Very rough materials in which there is more or less regularity of distribution give all forms of distribution curves and any distinctions between specular and diffuse reflection or transmission must be quite arbitrary. Nothing but the distribution curve itself can give an adequate description of the effect of the material on a beam of light. In particular classes of materials, brightness observations at particular angles give sufficient data for practical purposes as shown in the preceding and following reports. Some form of good brightness photometer, means of illuminating with a known source at a known angle and of observing at a known angle are essential.

THEORY OF DIFFUSION PHOTOMETRY.

Nomenclature.—In dealing with the theory of diffusion measurements it is convenient to depart somewhat from the accepted nomenclature of engineering photometry and define flux and brightness in the simplest physical terms.

[4] *Ph. Rev.*, 1914, p. 396.
[5] *Zeit Inst.*, 1914, p. 209.
[6] *Ph. Zeit*, 1912, p. 562.

Physically, light quantity is radiant energy times visibility. *Flux* is the rate in ergs per second (or in watts) times visibility at which light streams through or upon a given area. The *density* of this light stream, as it passes a given surface, is the flux per unit area. Its *concentration* is the flux per unit solid angle. A beam of light is made up of a great many pencils of light, hence the density of light on a given surface is the integral of the concentration over a hemisphere.

The *brightness* of a given surface to the eye, when viewed in a given direction, is proportional to the flux within a cone filling the pupil of the eye at one end and coming from an elementary projected area at the other and hence proportional to the light leaving a given projected area in a given direction. Brightness is then measured by the flux per unit solid angle per unit projected area of surface. The unit of brightness, the *lambert* is π candles per square centimeter of projected area.

Distribution Curves.—When a surface is illuminated by light of a known density and concentration, the readings of a brightness photometer sighted on it at various angles may be plotted as a function of angle B (α) giving a distribution curve. The scale of the photometer is checked by sighting it on a surface of known brightness; that is, a surface of known reflecting power, diffusion and illumination. The brightness photometer will then read in flux per unit solid angle per unit projected area on any surface viewed at any angle.

In practise the photometer is sighted on a block of magnesium carbonate whose reflecting power (about 86 per cent.) has been determined with an absolute reflectometer. When such a block is illuminated perpendicularly with a flux density D, the total flux outward is RD, R being the reflecting power of the surface. If the surface is perfectly diffusing, the flux density in a direction perpendicular to it at a distance r from it will be $RD/\pi r^2$ for each unit area of the reflecting surface. Hence the flux per steradian will be RD/π in that direction. Therefore, the brightness of the comparison block so illuminated will be in any direction RD/π flux units per steradian per unit projected area, *lamberts* for short. If, then the brightness photometer sighted on the surface measured reads B/R times as bright as on the

comparison block, the brightness of the surface is BD/π lamberts in that direction.

The angular relations involved are angle of view (α) and solid angle ω. In Fig. 1 let α be the half angle of a cone of solid angle ω intersecting the surface of a sphere of radius r. The area of the surface intercept is $2\pi r^2 (1 - \cos \alpha)$ hence $\omega = 2\pi (1 - \cos \alpha)$ and $d\omega = 2\pi \sin \alpha \, d\alpha$.

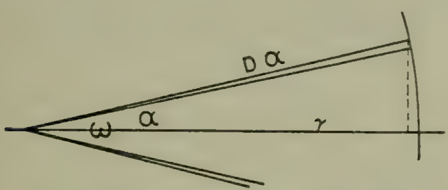

Fig. 1.—Solid angle and angle of observation.

Let the concentration of light in a narrow axial pencil be C coming from a small plane area of diffusing surface. Then the flux within a solid angle ω will be

$$F_\omega = \int_0^\omega C \cos \alpha \, d\omega = C\left(\omega - \frac{\omega^2}{2\pi}\right)$$

the element of flux dF within an element of solid angle $d\omega$ is therefore

$$dF = 2\pi C \sin \alpha \cos \alpha \, d\alpha$$

$$= C\left(1 - \frac{\omega}{\pi}\right) d\omega.$$

Our data then consist of a series of brightness readings $B(\alpha)$ at various angles and a single reading B_0 on a comparison block, the incident normal flux density F_0 being known. $B(\alpha)$ is plotted as a function of angle as in the middle curve Fig. 2. This is proportional to the emission per unit projected area, multiplied by $\cos\alpha$ it gives the lower curve, of which the ordinates are proportional to emission per unit area.

Multiplying further by $2\pi\sin\alpha$ gives the upper curve the ordinates of which is proportional to the light emitted in a cone element of which $d\alpha$ is a section and 2α the apex angle. This third curve is then $2\pi B(\alpha) \sin \alpha \cos \alpha$, which by the above equation is equal to $dF/Cd\alpha$ or the concentration of the emitted light divided by the flux density of the incident light.

In case the scatter is in one direction only, as is the case with ribbed glass for example, the integration is carried out directly in the plane angle without recourse to the solid angle. When the reflected or transmitted light is symmetrical about neither the axis nor a plane, integration is rarely required in practise. Distribution curves may, of course, be determined at any orientation of the sample and mean reflecting power found with the ring reflectometer. Should further data be required, the distribution curves for different orientations may be summed by plane angles.

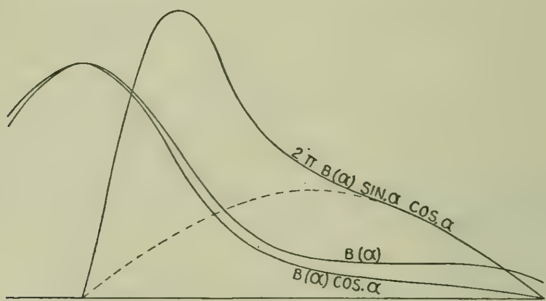

Fig. 2.—Brightness and angular radiation.

The graphical integration of the brightness curve by this process is perfectly general, applying to even specular reflection and transmission. Reflecting power or transmission coefficient at a particular angle is a meaningless term but mean reflecting power and mean transmission are perfectly definite quantities. The integration of both the reflected and transmitted light gives the absorption with quite satisfactory precision by this method. Total reflection and transmission require further integration for extended sources.

Extended Sources.—Having obtained the distribution curve for normal illumination (source of small angular extention), the distribution curve for a more extended source of known brightness is easily calculated. If the brightness of the source in the direction of the sample is B_s lamberts, then unit area of the latter receives B_s/π light units per unit area from each unit area of the source. Hence the distribution curve for the extended

source is the sum of distribution curves for the elements of the source.

When the source is so large as to extend quite an angle from the normal to the specimen and that is not highly diffusing, or in case the specimen reflects unequally in different directions (ribbed glass and textiles with a nap are examples) then several distribution curves must be determined by observation. Data on a few such cases will be given in the following report. In Fig. 3 are shown for illustration, curves obtained on glossy paper with

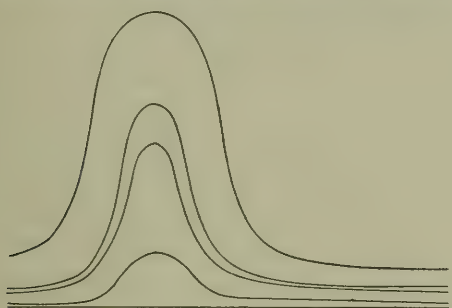

Fig. 3.—Distribution curves with extended sources.

wider and wider sources.

Lens Systems.—The intensity and distribution of light in image forming optical instruments is of importance in many practical problems. There are two principal cases to be considered (1) object self-luminous or illuminated from in front and (2) object illuminated from the rear by a condenser system, an image of the light source being formed at the projecting lens.

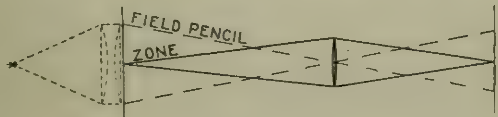

Fig. 4.—Direct and projected images.

In the first case the object has a certain brightness in the direction of the first lens. The light flux is constant through all the series of zone pencils through the system except for light losses in the lenses themselves. The same is true of the field pencils. Hence the relative flux density in image and object is

the percentage transmission of the system times the solid angle of the final zone pencil. The brightness of the image on the other hand is the brightness of the object, as viewed from the first lens, times the percentage transmission of the system.

In the second case the brightness of object is its transmission coefficient times the flux per unit area and this latter is the angular flux density divided by the square of the distance from the source to the Gauss point of the condenser (roughly the focal length of the condenser). Given the brightness of object found in this manner, the brightness of the image and the flux density in the plane of the image are found as in case one.

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DIFFUSING MEDIA III. PAPERS AND INKS.*

Synopsis: This report covers print papers; mat, semi-glossy, glossy; sizings, fillers, inks; writing papers and inks; typewriter papers, inks and carbons; drawing papers and inks; tracing papers and cloths; blue print papers; photostat papers. Data are given for specular and diffuse reflecting power and brightness, diffuse transmission and opacity, contrast ratio, back reflection, entrant and exit scatter and other properties.

Print Papers and Inks.—The untinted print papers differ chiefly in reflecting power (whiteness) and gloss. The reflecting powers of the newspaper papers, unfilled and not very opaque, run as low as 50 per cent.; medium grade papers, just perceptibly grayish, reflect 60 to 70 per cent., while the whitest, finest grade papers reflect as high as 83 per cent. Thin papers of low opacity often reflect much less than 50 per cent.

The proportion of light specularly reflected varies from practically nothing up to 5 per cent. in the case of the highly glazed plate papers. There is a wide variety of half gloss papers. When the surface is dulled by putting a thin mat overcoat on a glossy paper, the specular angle is small and the paper has a subdued brilliancy and gives but slight glare. On the other hand, paper that is heavily filled and calendered but unglazed has a wavy surface that gives a bad glare on account of the wider angle of specular reflection.

Print inks vary from dead mat to very glossy. The mat inks vary in reflecting power from 3 to 4 per cent. The glossy inks, if coated on a smooth hard surface reflect about 3 per cent. specularly and 0.8 diffusely. If used on a rough or strongly absorbent paper, they reflect more diffusely and may even appear quite mat. The glare from glossy ink is particularly objectionable in the larger cuts usually printed on glossy plate papers.

Typical distribution curves for the various classes of print papers are shown in Fig. 1. Curve No. 1 is from a mat paper[1] of 63.6 per cent. reflecting power; No. 2, an unglazed book paper of good quality; No. 3, a heavily calendered glazed paper, while No. 4 is a glossy plate paper. These curves are taken with a

* Report No. 4 of the I. E. S. Committee on Glare.

[1] Warren's cameo, paper.

disk source subtending a solid angle of 0.01 and perpendicular illumination.

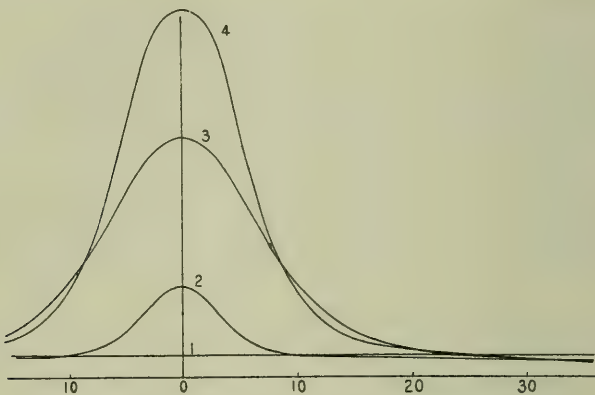

Fig. 1.—Distribution curves of print papers.

	Total reflecting power	Specular reflection	
No. 1. Mat.	0.636	0.002	Warren "Cameo"
No. 2. Slightly glossy	0.575	0.016	Jour. Wash. Acad.
No. 3. Semi-glossy	0.633	0.031	Warren "Cumberland"
No. 4. Glossy	0.636	0.037	Kodak park plate.

In the figure only the portion of the distribution curves near the specular angle are given. The reflecting powers given are integrals of the distribution curves obtained as outlined in Report No. 3. The specular reflection given in the table above was obtained by integrating the excess over a smoothed cosine curve.

In the table below are listed optical data on a number of print papers ranging from newspaper to the heaviest plate papers. These data are given by way of illustration of the desirable properties and as means of drawing comparisons between papers more or less familiar to all readers. They were taken with a spectrometer with brightness photometer attachment.

From the reader's point of view, print paper should possess a high reflecting power and but little gloss and the print or cuts on the back should not show through. In the first column marked R_d is given the *diffuse reflecting power* of a single thickness of the paper; in the following column (R_∞) that of a pile of the paper

so thick that adding more would not increase the reflecting power of the first surface. These reflecting powers determine the brightness when illuminated with a given source. In the third column R_s is given the *specular reflecting power*, in column G following the *gloss* or ratio of specular to diffuse brightness with a normal illumination subtending 0.01 steradian (10 cm. square at 1 meter).

Paper	R_d	R_∞	R_s	G	t	T	B	D	D_1
Weather Review	0.55	0.63	0.000	0.02	0.109	0.178	0.0143	0.405	3.72
Science Abstracts	0.58	0.616	0.000	0.01	0.091	0.171	0.0120	0.394	4.32
Science	0.62	0.640	0.001	0.03	0.118	0.111	0.0047	0.523	4.44
Analen der Physik	0.540	0.600	0.008	0.47	0.063	0.223	0.0023	0.328	5.21
SitzungsberichteWien (index)	0.35	0.57	0.002	0.21	0.038	0.405	0.1070	0.208	5.47
SitzungsberichteWien (text)	0.55	0.59	0.005	0.30	0.061	0.194	0.0170	0.353	5.78
Industrial Arts Index	0.533	0.566	0.003	0.15	0.53	0.24	0.027	0.290	5.48
"Light," Ill. Eng. Soc.	0.62	0.633	0.001	0.04	0.128	0.067	0.0017	0.760	5.65
Brittanica, India Paper	0.59	0.62	0.000	0.02	0.048	0.215	0.019	0.280	5.82
Bible Paper	0.575	0.61	0.000	0.02	0.048	0.21	0.187	0.305	6.34
Astrophysical Jour.	0.605	0.617	0.009	0.44	0.112	0.07	0.002	0.750	6.70
Rochester Herald	0.50	0.51	0.001	0.06	0.09	0.116	0.0067	0.644	7.14
Shap Shots	0.580	0.60	0.02	1.80	0.083	0.096	0.0039	0.628	7.56
Amer. Machinist (cov.)	0.577	0.585	0.019	0.98	0.125	0.05	0.0011	0.956	7.65
Amer. Machinist (text)	0.550	0.57	0.019	1.00	0.078	0.10	0.0045	0.670	8.58
Photographic Jour.	0.57	0.583	0.013	0.11	0.095	0.081	0.0028	0.729	7.67
"Cumberland" (Warren)	0.595	0.598	0.03	1.26	0.117	0.046	0.0009	0.946	8.08
Inland Printer (text)	0.60	0.625	0.021	1.12	0.083	0.081	0.0026	0.680	8.18
Inland Printer (plate)	0.58	0.50	0.023	1.22	0.119	0.042	0.007	0.988	8.30
E. K. Co. Bulletin	0.590	0.60	0.037	1.89	0.123	0.038	0.0006	1.032	8.38
Jour. Wash. Acad. Sci.	0.57	0.50	0.016	0.50	0.088	0.75	0.0024	0.752	8.55
Moving Picture World	0.555	0.565	0.015	0.78	0.073	0.113	0.0059	0.602	8.25
Modern Sanitation	0.59	0.595	0.037	1.89	0.101	0.056	0.0013	0.870	8.60
Central Zeitung	0.55	0.60	0.006	0.38	0.053	0.17	0.013	0.414	7.80
Engineering World	0.575	0.592	0.01	0.52	0.074	0.115	0.0056	0.668	9.00

The *thickness* of the samples is given in column *t* in fractions of a millimeter, the *percentage transmission* in column T. Most papers absorb from 75 to 95 per cent. of the incident light not reflected, 1 — T being the absorption. Column B is $T^2(1 - R)$. Of the incident light, the fraction R is reflected and 1 — R enters

the paper, $T(1 - R)$ reaches the back face. If a similar sheet underlies the first $TR(1 - R)$ re-enters the back of the first sheet and $T^2R(1 - R)$ emerges from its front face (see report Diffusing Media I). The brightness of the front face depends upon the sum of the light reflected from this face and the light reflected back from underlying sheets or $R + T^2R(1 - R)$. Hence if T^2 is small and R is large, $1 + B$ is the relative brightness of plain paper and paper inked on the back. If B, the back reflection, is greater than half a per cent. (0.005), print on the back will show through quite perceptibly. No paper should be used except for special purposes for which B is greater than 0.02, if B is 1 per cent. (0.01) the transparency is annoying.

Density $D = -\log T$, in the next column, is a quantity proportional to the thickness and a proper measure of the *opacity* of a paper. $D_1 = (-\log T)/t$, the *specific density* or the density per unit thickness, is a measure of the quality of the paper material. It depends largely upon the quality and the amount of filler used.

Reflecting powers range from about 50 per cent. for the newspapers up to nearly 70 for Nos. 4, 7, 8 and 16. These are slightly cream tinted papers; No. 6 is by far the whitest paper of any but has a lower reflecting power probably on account of blue used to counteract a slight yellow. The back reflections vary from practically nothing (20) up to 0.121 in No. 5, a very thin transparent paper. Specific densities range from 3.7 up to a fairly definite maximum at from 8.5 to 9.0.

Fillers.—Fillers are used to give the paper opacity as well as to give it certain mechanical properties. Good filler should then possess high specific density and high reflecting power. Kaolin is largely used for the cheaper and medium grade paper, baryta for the most expensive papers. Both reflecting power and opacity increase with dryness and with increasing fineness of particle[2] until the particle is smaller than a light wave. The ideal filler would be a mass of non-hygroscopic transparent crystals about 0.0002 mm. in mean diameter and free from smaller and larger particles since these would tend to lower both opacity and reflecting power.

[2] TRANS. I. E. S., 1914, p. 593.

The reflecting powers of fillers vary from 60 per cent. or lower up to over 80 per cent. Their specific densities are approximately: kaolin, dry powder, 1.96; magnesium carbonate block 0.35, powder, 0.61; barium sulphate powder, 2.30.

Glazes.—The glazing material chiefly used is an inferior grade of gelatine with a refractive index of about 1.36 and a specular reflecting power of 2½ per cent. Any glazing is entirely deleterious optically, but it is considered necessary in some forms of paper to give a smoother surface and to prevent too free penetration of the ink.

Inks.—Print inks differ in specular and diffuse reflecting power. All are so opaque that the twice transmitted light reflected from the underlying paper is quite negligible wherever the ink actually covers the paper. Glossy inks are preferred for their somewhat better working qualities. Optically, the glossy inks have lower diffuse reflecting powers than the mat inks, hence are blacker and present a greater contrast with the paper. The mat inks are preferable only in the complete absence of glare. The following data indicate the properties of some characteristic printing materials.

	Diffuse ref. power			Rel.	Dens.	Back
	Paper	Ink	Contrast	trans.	of ink	reflection
1. Ord. print paper and ink	0.59	0.025	23.6	0.03	1.52	1.05
2. Jour. Am. Soc. Mech. Eng.	0.61	0.043	14.2	0.13	0.89	1.03
3. Snap shots	0.63	0.047	14.0	0.12	0.92	1.02
4. Calender	0.59	0.030	19.8	0.04	1.40	1.08
5. "Light," its use and misuse	0.65	0.037	17.5	0.10	1.00	1.00

The relative transmission, fourth column, is the ratio of the light transmitted through paper and printed character to the light through the paper alone. The density of ink, fifth column, is the negative logarithm of this ratio. The density per millimeter (specific density) of print inks are too high to measure with any precision (about 60) and of little interest. The back reflection, last column, is the relative brightness of paper alone and paper printed on the back, the quantity computed in the table on print papers, above, plus unity.

The specular reflection of an ink depends upon the matness of the paper upon which it is printed. The following measurements were taken using a glossy ordinary ink and a mat ink each on

three supports; photographic film, a glossy plate paper and a mat paper.

	Reflecting power		
	Diffuse	Specular	Gloss
Glossy ink on film	0.008	0.034	430
Glossy ink on glossy paper	0.008	0.017	210
Glossy ink on mat paper	0.012	0.006	51
Mat ink on film	0.036	0.0024	2.9
Mat ink on glossy paper	0.036	0.0020	2.4
Mat ink on mat paper	0.037	0.0015	2.2

Specular reflection from ink is unobjectionable when below half a per cent. (0.005) and even glossy ink on a mat paper, not too fine grained, will not give serious glare. The glossy ink of the above table is seen to be about four times as black as the mat; that is, the diffuse reflecting power is only a quarter of that of the mat ink.

Writing Papers and Inks.—Writing papers differ from print papers as a class chiefly in the glaze applied to render it non-absorbent and prevent running of the ink. This glazing material (gelatin, dextrin, glue, resin or soap) being of low index (1.36 about) and transparent, has the effect of (*a*) slightly lowering diffuse reflecting power and (*b*) considerably increasing specular reflecting power. In other words, it tends to render the paper slightly grayer and much more glossy. Many writing papers, however, have so low a gloss as to be quite unobjectionable.

The data given below is of the same nature as that given above for print paper and is to be interpreted in the same way.

	R_d	R_∞	R_s	G	t	T	B	D	D_1
Linen finish ordinary	0.61	0.64	0.0030	0.21	0.13	0.127	0.006	0.48	3.71
Commercial ordinary	0.57	0.63	0.0024	0.17	0.07	0.173	0.013	0.40	5.72

Writing ink was tested when on a semi-glossy paper and when on a specular film support. The inks were a good ordinary pen ink (Buffalo Standard) and a carbon (Higgin's "Eternal Black").

	R_d	R_s	T	D
Ordinary iron ink on film	0.025	0.005	0.019-0.18	0.74-1.74
Ordinary iron ink on glossy paper	0.035	0.0000		
Ordinary iron ink on mat paper	0.054	0.0001		
Carbon writing ink on film	0.005	0.085	0.096-0.44	0.35-1.58
Carbon writing ink on glossy paper	0.027	0.004		
Carbon writing ink on mat paper	0.045	0.0012		

Typewriter papers, inks and carbons. Typewriter papers are quite similar to the print papers of medium grade with but little fillers and very little glazing.

	R_d	R_∞	R_s	G	t	T	B	D	D_1
Ordinary E. K. Co.	0.515	0.594	0.0006	0.05	0.10	0.180	0.015	0.432	4.32
Ordinary I. E. S.	0.50	0.565	0.0000	0.00	0.87	0.216	0.023	0.263	4.20
Tissue carbon paper	0.36	0.552	0.005	0.64	0.038	0.366	0.085	0.243	6.38

The ink impressions vary greatly in density. The data given below refer to what was considered a fair average density.

	R_d	R_s	G	T	D
Ordinary black ribbon ink	0.05	0.000	0.07	0.37	0.43
Ordinary blue ribbon ink	0.128	0.001	0.37	0.62	0.21
Ordinary red ribbon ink	0.160	0.002	0.25	0.55	0.26
Carbon paper	0.032	0.005	0.25	0.24	0.62

Drafting Paper and Ink.—Drafting paper contains somewhat more filler and sizing than print paper and less than writing paper. The data below refer to a good ordinary paper and to some of special quality.

	R_s	R_∞	R_s	G	t	T	B	D	D_1
Good ordinary	0.54	0.64	0.0005	0.04	0.117	0.222	0.023	0.3182	2.72
Special quality	0.62	0.64	0.0012	0.09	0.19	0.078	0.002	0.684	3.60

The India ink which the following data applies is of the ordinary prepared variety (Higgins).

	R_d	R_s	G	T	D
India drafting ink on film	0.013	0.037	284	0.017-0.47	0.33-1.82
India drafting ink on paper	0.029	0.002	5.3		

Tracing Cloth and Paper.—The most important optical property of tracing cloth is its transparency. Glare and reflecting power are of less consequence. The requirements are quite similar to those for window envelopes (Report 6) and the reverse of those for print paper. With tracing cloth, the most distinct possible view of the underlying layer is desired. The same high transparency is desired for printing. The necessary fabric used as a body, however, scatters light to a considerable degree. Tracing paper must be opaque enough to show well a drawing made upon it but so thin and transparent that prints may be made directly through it.

Different grades of tracing paper and cloth differ widely in

properties. Below are given distribution data on materials of about an average grade.

RELATIVE BRIGHTNESS.

	0°	5°	10°	15°	30°	45°
Tracing cloth, reflection	0.41	0.37	0.34	0.32	0.28	0.28
Tracing paper, reflection	0.77	—	—	—	—	75
	180°	175	170	165	150	135°
Tracing cloth, transmission	6.3	5.3	3.6	2.1	0.82	0.53
Tracing paper, transmission	0.87	—	0.76	0.69	0.57	0.46

These readings were taken with an illumination and a photometer scale such that the reading on a 100 per cent. perfectly diffuse reflector would have been 1.56.

With the same constant (1.56) the following data on a number of tracing cloths were obained.

	Cloths over black				R Over White	Contrast	B 45	B 135
	BO°	B 45	B 135	B 180	B 45	Ratio	BO	B 180
15817	0.78	0.39	0.41	3.7	0.79	0.49	0.50	0.11
P. 13	0.72	0.41	0.42	2.03	0.75	0.54	0.56	0.21
N. T. 7	0.88	0.38	0.60	3.3	0.78	0.47	0.43	0.18
15742	1.04	0.40	0.56	2.0	0.80	0.50	0.39	0.38
I 2	0.72	0.44	0.46	2.4	0.81	0.54	0.61	0.19
S 3	0.75	0.42	0.45	1.32	0.79	0.54	0.56	0.34
V 1	0.55	0.29	0.41	2.00	0.74	0,52	0.71	0.21
E. K.	0.51	0.24	0.41	5.0	0.74	0.33	0.48	0.08

The first four column give the observed brightness at the angles 0, 45, 135 and 180° from the (perpendicular) direction of illumination in a black walled room giving very little stray light. "B 45 over White" is the brightness of the cloth when backed by drafting paper of 64 per cent. reflecting power. The contrast ratio is the ratio of brightness over white to brightness over black. B45 : Bo is entrant scatter, B135 : B180 exit scatter. (See report No. 2.)

Blue print paper is of medium reflecting power and weight, mat and very absorbent. The equivalent density of the photographic deposit as compared with inks is of interest. The following data were taken on two samples, one of the very high grade, the other of inferior quality.

	R_d	R_s	B:W	T	D_b
High grade, white	0.58	0.0005	0.16	0.31	
High grade, blue	0.084	0.0004		0.088	0.56
Low grade, white	0.44	0.0010	0.13	0.35	
Low grade, blue	0.07	0.0009		0.106	0.51

The reflecting powers of the exposed (blue) parts run about 7 or 8 per cent., only about twice that of mat print ink. The maximum blacks of the regular photographic papers run from (glossy solio) 0.6 per cent. up to the 4 per cent. on the mat papers.

Photostat paper is a thin, inexpensive photographic paper. Data on two samples are given. These did not differ greatly in material but the "special" had been forced by a professional photographer to give maximum contrast.

	R_d	R_s	B/W	T	D*b*
Ordinary white (clean)	0.594	0.0014		0.26	
Ordinary black (exposed)	0.056	0.0004	0.094	0.056	0.68
Special white (clean)	0.594	0.0012		0.33	
Special black (exposed)	0.03	0.0003	0.51	0.03	0.85

The blacks are nearly as black as print ink while the contrast ratio of black to white runs as high as 20 for the carefully developed sample.

The following report is to deal with the regular photographic papers.

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F. H. Gilpin,
M. Luckiesh,
F. K. Richtmyer,
F. A. Vaughn,
P. G. Nutting, *Chairman.*

DIFFUSING MEDIA IV.—THE OPTICAL PROPERTIES OF PHOTOGRAPHIC PAPERS.*

Synopsis: Photographic papers vary in reflecting power from pure white to dense black and in gloss from a nearly pure mat to a high gloss. Practical methods of measuring and specifying reflection densities and sensitometric data are outlined, distribution analyses of various types are given, gloss and its determination are discussed, data are given on transmission densities and diffusion in photographic plates and negatives.

Aside from the fact that nearly every one is more or less of a photographer and interested in photographic prints, the investigation of the optical properties of photographic papers is of great interest because in this product is prepared a wide range of precisely reproducible gloss and because in each paper with its particular gloss, a wide range of diffuse reflecting powers may be produced by the photographic process. No other product offers such excellent material for the study of these two optical properties.

REFLECTING POWER.

Photographic papers unexposed or fixed without exposure reflect from 65 to 75 per cent. and this, of course, represents the lightest high lights possible in a print. A print reflecting but 50 per cent. is just noticeably grayish, 30 per cent. a medium gray, 3 to 8 per cent. a muddy black. The maximum blacks obtainable on any papers reflect diffusely less than 1 per cent.—just about as much as the blackest printer's ink.

In viewing a photographic print it is usually held nearly perpendicular to the line of sight. The practical measurement of reflecting power involves illumination at an angle of 45° and an observation of brightness in the direction normal to the surface. A print may be comfortably viewed under widely different angles of illumination, but 45° is considered a fair average direction for testing purposes. The photometer for small areas described by Jones and Nutting[1] measures reflecting power in this manner. This photometer has been used chiefly for testing photographic papers, in fact.

A set of readings of diffuse reflecting power taken on un-

* Report No. 5, I. E. S., Committee on Glare, 1914-15.

[1] TRANS. I. E. S., p. 611. vol. IX, (1914).

exposed and fully exposed papers is given below together with the maximum contrast ratio. The readings are relative to the reading on a perfectly diffusing surface of 100 per cent. reflecting power under the same illumination.

	Max. white	Max. black	Max. contrast
Azo A (Mat)	0.715	0.038	19
C (Glossy)	0.745	0.018	41
D (Semi-gloss)	0.65	0.029	22
E (Velvet)	0.70	0.023	30
F (Glossy)	0.70	0.013	54
G (Mat)	0.695	0.040	17
Glossy velox (reg.)	0.70	0.010	70
Solio	0.64	0.006	107

The maximum blacks are of about the same reflecting power as printer's ink (Report No. 4). It is interesting to note that while the whiteness appears to bear no relation to gloss, the maximum blacks are always deeper in the glossy than on the mat papers. Ordinary glossy printer's ink reflects (l. c.) less than a third as much diffusely as mat ink—3.6 against 0.8 per cent. The range is somewhat less than in the papers listed above, namely, 4.0 to 0.6 per cent.

The fact that the deeper blacks are obtained on the glossy papers and inks is possibly due to the fact that the light absorbing particles are covered with a coating of more or less transparent substance of about the same refractive index as themselves, hence there is little reflection at the interface. With mat surfaces, the absorption within the particles is of the same order but the surface reflection from the individual particles is so great that considerable light is scattered.

In a series of grays running from white to black made on photographic paper, the specular reflecting power remains constant or nearly constant while the diffuse varies by a factor of 20 to 100. Gloss then varies through the same range of values, gloss being defined as the ratio of specular to diffuse brightness.

In the sensitometry of photographic paper it is the diffuse reflecting power that is taken as a measure of the photographic effect. A series of about 20 exposures are made, each the square root of two times the preceding, by printing through carefully selected neutral gray film of the proper series of densities. After development the reflecting powers of the exposed spots are

measured relative to the adjacent white paper, the paper being illuminated at an angle of 45° and read perpendicularly. Reflection densities are taken as the common logarithm of relative reflecting power. This is not proportional to the mass of reduced silver as is the case with transmission densities (-log transmissions) except at the lowest densities. Specular reflection is ignored as it does not affect either relative exposure nor the deposit of silver. A typical series is given below. It is a test of the paper known as Artura Iris A. T is the transmission of the series of printing screens, D_p (= — log T) the corresponding printing densities (steps roughly 0.15), E the relative exposures, R_d the relative reflecting power of the print spots and white field adjacent, and D_r the reflection densities of the series.

Step	T	D_p	E	R_d	D_r
1	0.0025	2.709	1.0	1.0	0.0
2	0.0029	2.551	1.16	1.0	0.0
3	0.0045	2.385	1.80	1.0	0.0
4	0.0054	2.268	2.16	1.0	0.0
5	0.0077	2.127	3.08	1.0	0.0
6	0.0112	1.939	4.48	1.0	0.0
7	0.0157	1.803	6.28	0.97	0.015
8	0.0240	1.643	9.60	0.86	0.065
9	0.0308	1.510	12.32	0.75	0.125
10	0.0452	1.345	18.08	0.48	0.32
11	0.0434	1.364	17.36	0.565	0.25
12	0.0622	1.206	24.88	0.354	0.46
13	0.0912	1.040	36.48	0.220	0.66
14	0.1205	0.922	48.2	0.164	0.78
15	0.165	0.782	66.0	0.111	0.97
16	0.255	0.594	102.0	0.055	1.26
17	0.347	0.462	138.8	0.041	1.38
18	0.503	0.298	201.2	0.039	1.41
19	0.684	0.165	273.6	0.038	1.42
20	1.0	0.0	400.0	0.038	1.42

The sensitometer curve is D_r plotted as a function of log E. From this, speed, gradation and maximum gradient are read off.

GLOSS AND GLARE.

The distribution of the light reflected from four selected photographic papers is shown in Fig. 1 to illustrate the character and range of diffusion provided for. Curves were taken with illumination nearly normal and 0.01 in angle. The curve for Azo C is

plotted with half the ordinate scale of the others. The range in gloss is from an almost dead mat surface (G) to the extremely glossy C. Solio, regular glossy Velox and Azo F are of the same type as C but slightly more glossy. The specular projections on the curves for C and D are of the ordinary type such as is produced by varnish or by the calendering of print paper. E, however, shows the superposition of two distinctly different types of gloss, one of the ordinary type and the other of about three times the angle but of less maximum reflecting power.

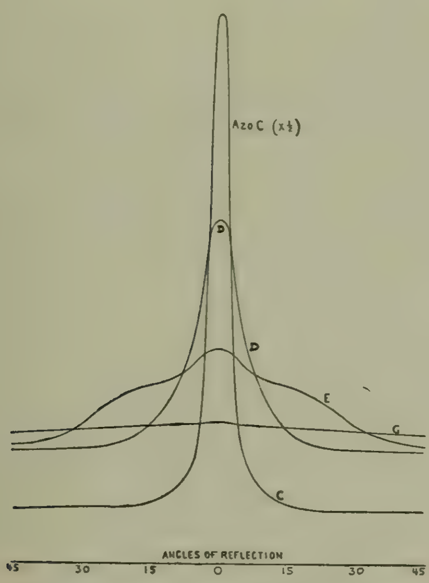

Fig. 1.—Distribution Curves of Azo C, D, E and G.

Viewed at the specular angle under a single bare lamp or other narrow angle illuminant, papers C and D show a small glare spot of about the same size but C brighter than D, while E shows a much larger spot. It is desirable to distinguish between the effects of (*a*) the maximum height of the distribution curve (*b*) the width and (*c*) the area of the projecting part of the curve representing specular reflection. The maximum height depends upon the brightness of the illuminating source, the width upon

the angular width of the source and the area upon both. Now, gloss defined as the ratio of specular to diffuse brightness, is a measure of height and is independent of width or area of distribution curve. On the other hand, total specular reflection, the area of the projecting area on the corrected distribution curve, is not a measure of either gloss or glare. For practical purposes it might be desirable in some cases to record the angular spread of light in the glare spot when a narrow source is used, but usually gloss is of chief or sole value in photographic papers. In diffusing globes it is the maximum spread that is particularly desired.

PHOTOGRAPHIC PLATES AND NEGATIVES.

Undeveloped photographic plates have a high turbidity and for blue light a high opacity. The emulsion with which the plate is coated is a yellowish white in color and roughly 0.02 mm. thick. It has a moderate surface gloss. Distribution curves plotted for Seed 23, 30 and lantern plates with white light gave substantially the same results. The brightness given is relative to that of a perfectly diffusing surface reflecting 100 per cent.

	Reflection					Transmission				
Angle........	15	30	45	60	75	105	120	135	150	165
Brightness ...	0.69	0.56	0.54	0.52	0.42	0.27	0.33	0.35	0.37	0.37

There is no specular transmission but a specular reflection of about 5 per cent. The density is about 0.2 in the yellow and very high in the blue, the density per millimeter is about 10 in the yellow.

In photographic negatives the absorbing silver grains are in the form of spongy black masses imbedded in transparent gelatine. A great deal of light is scattered in addition to that directly absorbed. Diffuse transmission is several times greater than specular. Diffuse densities determine exposures in contact prints, specular densities in projection printing and enlarging. Different plates differ in ratio of diffuse to specular densities. Different exposures on the same plate show the same relative densities in some plates and different in others, the variation being most marked in the coarse grained high speed plates.

Plate	Diffuse density	Specular density	$\frac{D_s}{D_d}$	R 45°
Seed lantern	0.47	0.77	1.64	0.050
	1.04	1.66	1.60	0.023
	1.69	2.67	1.57	0.022
	2.75	4.3	1.61	0.021
Seed 23	0.75	1.13	1.51	0.031
	1.68	2.51	1.49	0.021
	2.90	4.3	1.50	0.021
Seed 30	0.50	0.89	1.78	0.052
	1.12	1.85	1.65	0.025
	1.88	2.83	1.51	0.022
Seed graflex	0.55	1.17	2.18	0.051
	1.22	2.27	1.86	0.028
	1.78	3.12	1.67	0.028
Cine pos. film..........	0.06–2.11	0.10–3.30	1.58 (mean)	—

The reflected and transmitted light is not uniformly distributed. The following data taken on a medium exposure on Seed 23 is typical:

Angle	15	30	45	60	75	105	120	135	150	165
Rel. brightness	1.7	0.60	0.39	0.32	0.26	0.079	0.128	0.25	0.50	1.96

The sensitometry of plates by the Hurter and Driffield method is described in treatises on photography and applied optics.

Considerable data of related interest on the specular and diffuse reflecting powers of ordinary papers is contained in our report No. 4 on papers. General relations and definitions are given in our general report, No. 1, and in report No. 2 on diffusing media.

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WINDOW ENVELOPES.*

At the request of a letter carriers' association the Committee on Glare of the Illuminating Engineering Society has undertaken an investigation of the optical properties of the various kinds of window envelopes now in use. About 100 samples of used envelopes were submitted by the letter carriers' association for the tests. The determinations were made in a well equipped optical laboratory under the personal supervision of the Chairman of the Glare Committee on about 25 carefully selected samples. A classification of material, the conclusions drawn and the more important data obtained are given below:

In the window envelopes in question the windows are of the following four classes:

1. An oblong *hole* without any covering.
2. A window covered by an insertion of clear, *transparent film* usually of gelatin.
3. A window covered by a *translucent insertion* of special oiled paper.
4. The window is merely an oiled or varnished portion of the *envelope* itself. The envelope is frequently of heavy blue or yellow paper.

The essential properties of these four forms of windows are those outlined below:

1. The open window is visually equivalent, except for a slight bordering shadow, to viewing the address directly. The slight bordering shadow occurring sometimes under poor illumination has no ill effect of any consequence on vision.

2. The window of clear film causes:

(*a*) A general lowering of brightness of the address by about 10 per cent. This is equivalent merely to a lowering of illumination by that amount for any angle of view except the angle of specular reflection.

(*b*) Occasional specular glare, very bright except for very diffuse indirect lighting. This glare spot is about one-hundredth to one-tenth as bright as the source of light whose image is reflected. It is very bright indeed when bare lamps are used as il-

* Report No. 6 of the Committee on Glare of the Illuminating Engineering Society.

luminants. The diffuse brightness of the address read is determined simply by the illumination at that point and the diffuse reflecting power of the paper, and is thus very nearly independent of diffuseness of the illumination and the angle of view.

(*c*) Clear windows produce no noticeable decrease in contrast or in definition except at the angle of glare.

3 and 4. Windows of translucent materials cause:

(*a*) A slight general lowering of brightness due to loss of light by specular reflection from their surfaces of the same order as that caused by clear windows. (See 2a.)

(*b*) A specular glare similar to 2b.

(*c*) A veiling effect (superposed brightness) due to light diffusely reflected from the material of the window. This causes a serious lowering of contrast to about $^1/_{10}$ its value in the uncovered address (see data below).

(*d*) A veiling due to diffuse transmission through the window. This causes at best a serious loss of definition rendering the address quite illegible in the worst cases even under good illumination and with the window pressed close to the address.

We have made the following measurements on selected samples of the various classes of window envelopes. A strip of mat black paper was placed on mat white paper (except in tests Nos. 3 and 8) and the reflecting power of each determined behind each window:

		Reflecting power		
		White per cent.	Black per cent.	Contrast ratio
Test No. 1.	Bare test pieces	68.0	2.1	32.4
2.	Clear gelatine window	61.3	2.8	22.0
3.	Ditto, ink on brown paper	43.0	18.0	2.4
4.	Oiled tissue paper (class 3)	61.0	15.0	4.1
5.	Ditto, another sample	61.0	11.5	5.3
6.	Envelope, oiled (white, class 4)	49.0	14.0	3.5
7.	Ditto, blue envelope	35.0	9.0	3.9
8.	Ditto, ink on bluish paper	18.5	9.0	2.1

It is to be noted that the oiled and varnished paper windows increased the apparent brightness of the black strip from 5 to 9 times and decreased the contrast by from 8 to 10 times.

The diffusing properties of these window materials were further determined by the ordinary methods. Each sample is

illuminated perpendicularly by a collimated beam of light. Then its brightness is measured at angles of 45, 135 and 180° from the incident beam. The unit of brightness is that of a diffuse reflector reflecting 100 per cent., magnesium carbonate reflecting 88.0 per cent.

Material	Rel. brightness at 45°	135°	180°	$\frac{B45}{B135}$	$\frac{B135}{B180}$
Oiled tissue (c. f. No. 4)	0.45	0.62	165	0.73	0.0026
Oiled env. white (No. 6)	0.52	0.74	38	0.70	0.0051
Ditto, blue (No. 7)	0.12	0.40	61	0.30	0.0015

The specular transmission of each sample was zero. No light was transmitted directly through. The scatter is from ⅛ to ½ as much as is caused by a perfectly diffusing surface.

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DIFFUSING MEDIA VI.—INTERIOR FURNISHINGS.*

Synopsis: In this report are discussed the optical properties of walls, woodwork, ceilings, floors, fixtures, shades, draperies and furniture as dependent upon the raw material, the finish and the covering. Attention is given largely to the general properties necessary to minimize glare consistently with good illumination. The relation of illumination to the properties of furnishings is considered in each case.

The proper choice of surfaces for house and office furnishings to provide a maximum of eye comfort involves not only the surfaces themselves but their positions relative to illuminant and inhabitant and the character of the illuminant. The condition desired is not necessarily the elimination of all glossy surfaces but an arrangement such that no glossy surfaces are in a position to cause objectionable glare. In other words, the desired condition is one of no glare rather than of no gloss. A gloss that would be intolerable in a table top is of no consequence in a baseboard, fireplace or ceiling, since from plane surfaces placed as these are, under ordinary conditions, no specularly reflected light can enter the eye.

Limits of tolerance are discussed in the general report (Report No. 1) on classes of glare and means of suppression. The classes of glare involved in houses and offices are:

(1) *Brightness Glare.*—Excessive brightness such as occurs with sun shining directly on snow, white paper or a white window shade. The limit of tolerance depends upon (*a*) the state of brightness accommodation of the eye due to the general brightness of the surroundings and (*b*) upon the angular area of the bright surface viewed. Some measurements indicate that the product of brightness and area, that is the total candlepower of the bright object viewed, would be a better measure of brightness glare than mere brightness alone. Possibly some simple function of both brightness and area will ultimately be chosen as a measure of this kind of glare.

(2) *Contrast Glare.*—Contiguous bright and dark objects cause disturbance of vision if their relative brightness is exces-

* Report No. 7, I. E. S., Committee on Glare, 1914-15.

sive. A bright illuminant viewed against its background, a dark window frame against sky or a bright landscape and a glare spot on a glossy surface are familiar examples.

At moderate and high intensities a relative brightness of 100:1 or over is uncomfortable and is to be avoided. Ordinary print on white paper presents a contrast of about 20:1. When the darker part of the field of view is but little lighter than complete darkness (a hole in a black lined box, say) then relative brightness may be very high without producing an objectionable effect. This begins when the brightness of the brighter area is over a fixed value, considerably less than the limit in case the whole visual field is bright (case 1 above) or is free from excessive contrasts.

The limit of tolerance in contrast glare is somewhat lower the shorter the line of contact between the neighboring surfaces showing excessive contrast. In specifying contrast glare it is, of course, *total* brightness (specular plus diffuse) which is to be considered.

(3) *Veiling Glare.*—By veiling glare is meant that condition in which the surface to be observed appears covered with a light or dark veil of a different or imperceptible pattern. A picture or polished wood viewed from near the specular angle, a landscape viewed through a window screen or dirty window are familiar examples. Bright veiling is measured by relative contrast; that is, by the ratio of contrast with veiling to contrast without veiling.

Walls and Wall Coverings.—Walls of rooms may vary widely in reflecting power, hue, shade or gloss. A low diffuse reflecting power means, of course, a dead loss in illumination, but white walls highly illuminated lead to mild visual discomfort. Gloss in the middle levels may lead to a highly objectionable glare, but if near the floor margins or ceiling no specularly reflecting light can reach the eye. With totally indirect illumination considerably more gloss may be tolerated, since the light specularly reflected from glossy walls is reflected downward at a much larger angle than under direct or semi-indirect illumination.

But little data on wall coverings of general value can be given on account of their widely varying nature.

	Reflecting power	
	Diffuse	Specular
Raw plaster	0.40–0.50	0.0
Finished plaster	0.60–0.70	0.005–0.020
Fine white washes	0.70–0.84	0.0
White tile, marble	0.50–0.70	0.0 –0.05
White paint	0.40–0.60	0.05
Finished wood—light	0.12	0.04
Finished wood—dark	0.06	0.04

Aside from esthetic considerations, perhaps the ideal wall covering from the standpoint of economy and eye comfort would be one free from gloss throughout and varying in diffuse reflecting power from 30 per cent. near the floor to 80 per cent. near the ceiling. The high reflecting power above saves light and does not greatly affect vision, the low reflecting power below avoids eye fatigue. A reflecting power as low as 10 per cent. or less on the lower part of a wall would not only waste light but be slightly uncomfortable to an eye accommodated to the brightness of white paper.

Ceilings.—That ceilings should be white and of high total reflecting power is widely recognized in practise. In all ordinary cases the sole consideration is economy of light since they are above the ordinary level of vision. In very large rooms a glossy surface is to be avoided since in such cases troublesome glare within the line of vision may occur. Diffuse reflecting powers of 70 to 80 per cent, are readily available in papers, washes and paints.

Floors.—Floors are constantly within the range of vision and a moderate to low reflecting power is preferable. Near the walls, gloss on a floor is quite unobjectionable since no specularly reflected light can reach the eye. Near the center of the room uncovered, glossy floors are intolerable. The common practise of covering the centers of floors with rugs is an excellent one, since rugs are usually very mat and of but moderate reflecting power.

But little reflection data on floor materials, finishes or coverings can be given on account of their variability. The following data refer to oak of about an average tint:

	Reflecting power			
	Red	Green	Blue	White
Oak oiled diffuse	0.074	0.046	0.012	0.053
Oak oiled specular	0.036	0.042	0.032	0.039

Maple has about the same reflecting power as oak, perhaps a little higher on an average. A fresh surface on soft pine reflects 15 to 40 per cent., white tiling and marble reflect about 60 per cent.

Furniture and Fixtures.—In the finishing of furniture and fixtures, common practise is bad, in that glossy surfaces and uncomfortable glare are commonly met with. Varnished and polished tables and chairs near the center of a room can hardly fail to present bad glare spots to anyone in a room unless the illumination be totally indirect and in this case much of the beauty of the wood is lost in the overlying gray veil. Metal or metal painted fixtures and gilded picture frames are quite as bad, or worse, since their reflecting powers are higher than that of varnish. A little dull finished furniture is on the market and it is to be hoped that it will meet with increasing favor. Metal coverings of low gloss are not common but could no doubt be developed. The relative specular and diffuse reflecting powers of metals run about as follows:

	Reflecting power	
	Diffuse	Specular
Brass polished	0.018	0.46
Copper polished	0.03	0.21
Nickel polished	0.003	0.70
Aluminum paint	0.29	0.22

The amount by which the reflecting powers of brass are spectrally selective is shown by the following table:

	White	Red	Yellow	Blue
Diffuse	0.018	0.017	0.023	0.014
Specular	0.46	0.45	0.45	0.39

The reflecting powers of finished mahogany surfaces average about 4 per cent. diffuse and 5 per cent. specular. The diffusely reflected light is practically all red, while the specular is nonselective.

Window Shades, Curtains and *Draperies.*—The requirements for window coverings are similar to those for wall coverings on north exposures. Where exposed to direct sunlight only very opaque shades, and curtains and draperies of very low reflecting power should be used, otherwise they become at times intense sources of light directly at the level of vision. A double coated shade, black outside and of a color harmonious with the prevailing tones of the room inside, is to be chosen.

General Remarks on Furnishings.—Considered from the standpoint of gloss and glare, *ideal* furnishings should show (1) a general decrease in diffuse reflecting power from 80 per cent. on the ceiling down to about 20 or 30 per cent. on the floor and (2) no gloss anywhere except (if desired) above the eye level on the ceiling and near the angle of floor and wall, a location from which no glare, under ordinary conditions, can reach the eye.

Common practise is good in regard to the first of these conditions but very bad in regard to the elimination of specular reflection. In dwellings there is wide latitude for improvement; in auditoriums, stores, factories and machine shops conditions are much more difficult to deal with, but general practise is better developed.

Illuminants.—From the standpoint of glare alone, the rule to be observed is to keep intense sources of light well above the visual level. The fault commonly met with is not insufficient light so much as improperly placed sources of light.

Artificial light sources are easily dealt with, thanks to the variety of lighting units and fixtures available. The subject is discussed at length in the illumination primer[1] published by this society. On the other hand, common practise in day illumination is bad and the proper arrangement of window lighting quite difficult in most cases. Ordinary window lighting is bad, in that it is largely at the level of vision and that it is surrounded by relatively deep shadow. The remedy for these conditions would be to cut off the light entirely at the level of vision and illuminate the room solely by light from the upper part of the window. However, the loss of view involved would hardly be tolerated. The light from the sky quadrant available passing the upper sash is easily thrown on the ceiling and used to illuminate the room in an ideal manner by the use of an inclined mirror or a plain white surface. To partly avoid excess illumination at eye level without cutting off the view, a sill shade may be drawn up when conditions are worst or the window may be supplied with yellow or amber glass. This is quite effective in suppressing sky glare and actually brightens rather than dims a landscape.

The nature and definitions of the various classes of glare are

[1] "Light: Its Use and Misuse", (7th ed. April, 1915).

dealt with at greater length in the Report No. 1. The general properties of diffusing media are dealt with in the first report on diffusing media, while considerable data on the reflecting power and gloss of papers is contained in Report No. 4 on papers.

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SUBMARINE PHOTOGRAPHY.*

BY J. E. WILLIAMSON.

The taking of pictures under and through water has been attempted by several investigators—notably, M. Louis Boutan, Mr. Jaques Reighard of the University of Michigan, Mr. Etienne Peau and Dr. Francis Ward of Eipswich, England. Of these, Dr. Ward had the best results. On his estate in England he con-

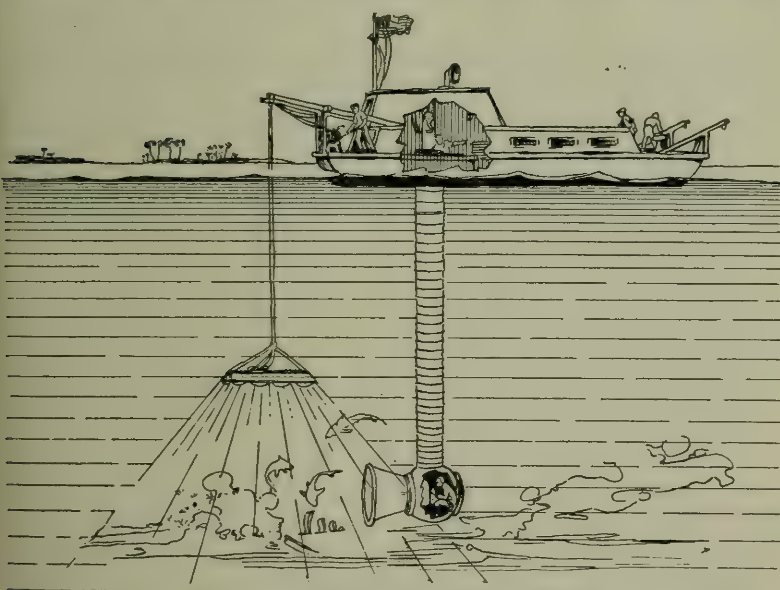

Fig. 1.—A tube used in submarine photography.

structed an artificial pond, having a cement well with a large plate glass window at one side of the pond. As a result of his experiments he stated that he believed under the most favorable conditions it would be possible to photograph through 3 feet (0.91 m.) of water.

The actual taking of the pictures is not difficult. The main

* Abstract of a paper read at a meeting of the New York Section of the Illuminating Engineering Society, January 14, 1915.

requisite is to get beneath the water and be able to remain there in comfort under normal atmospheric conditions. The author and his associates[1] have accomplished this by means of the Williamson submarine tube (Fig. 1). This consists of a water-tight collapsible tube, containing a chamber at its lower end of sufficient size to hold a man and a camera. The tube is lowered through an opening in the center of a boat specially constructed for this purpose. The chamber has a heavy glass plate to withstand the water pressure. Through this plate photographs can be taken. In the West Indies, where the water is very clear, both day and night pictures have been taken at considerable depths, which show objects clearly at distances of 100 feet (30.5 m.) from the camera. Daylight illumination, coming down through the water, is supplemented by the light from a bank of quartz-tube, mercury-vapor, arc lamps, which are placed in special water-tight housings and lowered over the stern of the ship. Fig. 1 shows a diagrammatic sketch of the apparatus in service.

[1] Williamson Submarine Film Corporation.

STREET LIGHTING WITH MODERN ARC LAMPS.*

BY W. P. HURLEY.

Arc Lamp Development.—The original commercial arc lamp system used for street lighting in America was of the open arc type, which came into commercial use about 1880. This lamp was usually operated in series on a direct current from special arc lighting generators. These lamps gave a very unsteady light with relatively high maintenance cost, due to the short carbon life and frequent trimming.

The enclosed carbon arc lamps for both alternating current and direct current came on the market about 1890 and were very popular in America because they were much steadier than the open arcs; and, owing to a carbon life of from 100 to 150 hours, requiring less labor, were much more economical to maintain. Their efficiency, however, was slightly less than the open arc.

The metallic flame or magnetite arc lamp was developed about 1906; it was essentially a low current, long-burning lamp of comparatively high efficiency. Owing to the nature of the electrodes, however, it could be made only for direct current. By reason of its very economical maintenance and good efficiency, many thousands of the previous types of arc lamps were superseded by this lamp, and it remained as the highest type of arc lamp development for the lighting of residence streets.

Flame carbon arc lamps were first developed in Europe and marketed about 1906. These lamps were very expensive, burning from 10 to 17 hours with comparatively expensive carbons, so that their use for street lighting in America was never very popular.

In 1911 a long-burning flame carbon arc lamp was developed, this being more in the nature of an enclosed arc lamp to burn impregnated carbons, with special devices for steadying the arc and keeping the globes clear of deposit from the arc. The long-burning flame carbon arc lamp is inherently of very high efficiency and, as the energy cost in any street lighting system is

* Abstract of a paper read before the Pittsburgh Section of the Illuminating Engineering Society, May 7, 1915.

The Illuminating Engineering Society is not responsible for the statements or opinions advanced by contributors.

approximately 50 per cent. of the total cost, including interest and depreciation on the equipment, it can be readily seen that where this unit is adapted its extremely high efficiency makes it superior to any other type. The lamp is inherently of high candlepower and cannot be practically applied where low intensity is required. It is suitable for either alternating or direct current and admits of a wide application.

For residence street lighting, the metallic flame lamp is recommended, as the intensity and color are most suitable for the usual requirements. Where very small lamps are required, as in outlying districts or alleys, small incandescent lamps should be operated in series with the arc lamps.

For business streets or "white way" lighting where relatively high intensities are required and the limitations of economy per unit are not so essential, as in residence districts, because the population per square foot of street area to be illuminated is higher, the flame carbon arc lamp is excellently adapted. It can be supplied in either a pendent or an ornamental post or bracket lamp, the mechanism being comparatively simple and practically the same in the two types.

For "white way" lighting, appearance of the street is the most essential. The arc lamp with its clear, white light contrasting favorably with the store window lighting always causes favorable comments. The intensity of the light is relatively high, so that large units can be employed profitably, thus reducing the number of poles and the first cost of the installation—at the same time taking advantage of the highest efficiency and economy in the use of energy.

Further developments in the way of luminous efficiency are most favorable to arc lamp development, as chemical limitations rather than physical are preeminent in this line, and the field of selective radiation of light has been as yet but slightly touched upon.

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THE EFFICIENCY OF THE EYE UNDER DIFFERENT CONDITIONS OF LIGHTING: THE EFFECT OF VARYING THE DISTRIBUTION FACTORS AND INTENSITY.*

BY C. E. FERREE AND GERTRUDE RAND,
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Synopsis: In a previous paper** a plan of work was outlined by one of the writers for the study of the effect of different kinds of lighting conditions on the eye. The problem was divided into three parts: (1) the determination of the conditions that give in general the highest level or scale of visual efficiency; (2) the conditions that give the least loss of efficiency for continued work; and (3) the determination of the conditions that cause the least discomfort. Tests were described especially designed to meet the requirements of each of these divisions of the work and results were given to show in a general way the sensitivity of the tests employed. The work of the present paper is confined to the second division of the problem and should be considered as an explorative investigation for the determination of factors. Six aspects of lighting are considered provisionally as sustaining an important relation to the eye: the evenness of the illumination, the diffuseness of light, the angle at which the light falls on the object viewed, the evenness of surface brightness, intensity and quality. Only the first five of these are dealt with in this paper. The first four are called, for convenience of reference, distribution factors. In order to produce the variation in the distribution factors needed for the purposes of the test, three types of reflectors in common use were employed—a direct, a semi-indirect, and an indirect. These reflectors were selected with reference to the object of the investigation rather than as representative in every case of any particular principle of lighting. The illumination effects produced in each case were specified in the following ways: (1) A determination was made of the average illumination of the room under each of the three installations. (2) The brightness of prominent objects in the room, such as the test card, the reflectors for the semi-indirect installation, the reading page, specular reflection from surfaces, etc., was given. (3) Photographs were made of the room from three positions under each kind of installation. These effects were then correlated with the results obtained with the eye test.

In order to determine the effect of varying intensity with a certain grouping of distribution factors, lamps of different wattage were used with each type of reflector employed in the distribution series. The

*A brief report of the work described in this paper was read by one of the writers (Ferree) at the seventh annual convention of the Illuminating Engineering Society held at Pittsburgh, September 22-25, 1913.

** TRANS. I. E. S., p. 40, vol. VIII (1913).

illumination effects produced were specified by illumination and brightness measurements in the way described above, and the effects were again correlated with the results of the eye tests conducted at each intensity of illumination.

I. INTRODUCTION.

In a paper[1] presented to the annual convention of this society last year, a plan of work was outlined by one of the writers for the study of the effect of different kinds of lighting conditions on the eye. The problem was divided into three parts: (1) the determination of the conditions that give in general the highest level or scale of visual efficiency, (2) the determination of the conditions that give the least loss of efficiency for continued work, and (3) the determination of the conditions that cause the least discomfort. Tests were described which seemed to the writer after six months of trial to be adequate for the requirements of each of these three divisions of work, and results were given to show in a general way the sensitivity of the tests employed. With the beginning of the present year work on the problem proper was begun. This work has been confined to the second division of the problem, namely, the determination of the conditions that give the least loss of efficiency as the result of a period of work. It has been thought best to conduct this investigation at first along broad lines in order to determine in a general way the conditions that affect the eye's ability to maintain its efficiency for continuous work. Later a more detailed examination will be made of the ways in which these conditions have been worked out in the various types of lighting systems in existence at this time.

The following aspects of lighting sustain an important relation to the eye: the evenness of the illumination, the diffuseness of light, the angle at which the light falls on the object viewed, the evenness of surface brightness, intensity, and quality. The first four of these aspects are very closely interrelated, and are apt to vary together in a concrete lighting situation, although not in a 1 : 1 ratio. For the purposes of this paper, therefore, which is the report of an investigation primarily explorative, it will be convenient to group these aspects together and refer to them as

[1] Ferree, C. E., Tests for the Efficiency of the Eye under Different Systems of Illumination and a Preliminary Study of the Causes of Discomfort; TRANS. I. E. S., 1913, Vol. VIII, pp. 40-61.

the distribution of light and surface brightness in the field of vision, or still more generally as distribution. In later work an attempt will be made to study the effect of varying each in separation, but in the work here reported upon, no especial attempt has been made to do this. The ideal condition with regard to distribution is to have the field of vision uniformly illuminated with light well diffused and no extremes of surface brightness. When this condition is attained the illumination of the retina will shade off more or less gradually from center to periphery, which gradation is necessary for accurate and comfortable fixation and accommodation. Up to the present time, we have been able to finish in as complete a way as we wish for the installations used the work on distribution and part of the work on intensity. The remainder of the work will be completed early in the course of the present year.

The factors we have grouped under the heading distribution can most conveniently be discussed with reference to four types of lighting in common use to-day: illumination by daylight, illumination by direct lighting systems, by indirect lighting systems, and by semi-indirect systems. In the proper illumination of a room by daylight we have been able thus far to get the best conditions of distribution. Before it reaches our windows or skylights, daylight has been rendered widely diffuse by innumerable reflections, and the windows and skylights themselves acting as sources have a broad area and a low intrinsic brilliancy, all of which features contribute towards giving the ideal condition of distribution stated above, namely, that the field of vision shall be uniformly illuminated with light well diffused and that there shall be no extremes of surface brightness. Of the systems of artificial lighting, the best distribution effects from the standpoint of the comfort and efficiency of the eye are, speaking in general terms, given perhaps by the indirect systems. In this type of system the source is concealed from the eye and the light is thrown against the ceiling or some other diffusely reflecting surface in such a way that it suffers one or more reflections before it reaches the eye. The direct lighting systems are designed to send the light directly to the plane of work. There is in the use of these systems a tendency to concentrate the light on the plane of work or object viewed rather than to diffuse it, and, therefore, a ten-

dency to emphasize brightness extremes in the field of vision rather than to level them down. Too often, too, the eye is not properly shielded from the primary source of light, and frequently no attempt at all is made to do this. The semi-indirect systems are intended to represent a compromise between the direct and the indirect systems. A part of the light is transmitted directly to the plane of work through the translucent reflectors placed beneath, and a part is reflected to the ceiling. Thus, depending upon the density of the reflector, this type of system may vary between the totally direct and totally indirect as extremes and share in the relative merits and demerits of each in proportion to its place in the scale. It is not our purpose, however, at this time to attempt a final rating of the comparative merits of types of lighting systems. For that our work is still too young. Moreover, there are relatively good and bad fixtures of each type, and good and bad installations may be made of any system. What we hope to do is by the appropriate selection and variation of conditions to find out what the factors are that are of importance to the eye in lighting, and from this knowledge as a starting point to work towards reconstruction.

It was stated also in our former paper that the problem dealing with loss of efficiency presents two phases. We may investigate (*a*) whether the eye shows a loss of efficiency after three or four hours of work under a given lighting system, and (*b*) whether there is progressive loss of efficiency in working several months or years under a given system. We have confined and purpose to confine our work for the present to the former aspect of the problem, because it alone falls within the scope of laboratory studies and because we believe that the problem should be worked out first in miniature with all the conveniences of manipulation and possibilities of precision obtaining under laboratory conditions.

II. THE EFFECT OF VARIATION IN THE DISTRIBUTION OF LIGHT AND SURFACE BRIGHTNESS ON THE EFFICIENCY OF THE EYE FOR A PERIOD OF WORK.

In order better to understand the data given in the tables of results, the nature of the tests used in this part of the work will again be briefly called to mind. It will be remembered that the conventional tests for the eye's responsiveness to its stimulus,

namely, tests for brightness sensitivity, color sensitivity, and visual acuity, were found to be practically useless for this work. Modified and rendered sensitive in the ways described in the previous paper, they were found to serve as a measure of the general level of efficiency of the unfatigued eye under different conditions of lighting; but they failed to show loss of efficiency as the result of a period of work. This is due to the following reasons. (*a*) There is doubtless very little, if any, loss of sensitivity to brightness and color during this length of time.[2] It is commonly believed, in fact, that the brightness and color processes are compensating in nature. And (*b*) the visual acuity test, in spite of the fact that its results may be ascribed practically entirely to changes in the muscular control of the eye, is not adapted to show loss in muscular efficiency, because the muscles of the eye, while they may have fallen off enormously in efficiency, can under the spur of the will be whipped up to their normal power long enough to make the judgment required by the test. But they can not long sustain this extra effort. This consideration, it will be remembered, led us to continue the test through an interval of time. After considerable experimentation an interval of three minutes was chosen as best suited for our purpose. When the observer is required to look at the test card for three minutes, the test objects, even when the eyes are fresh, are not seen clearly for the whole time. They are seen alternately as clear and blurred. The time they are seen clear and blurred is recorded on a rotating drum upon which a line registering seconds is also run. From this record the ratio of time seen clear to time seen blurred is determined. This ratio may be fairly taken as a measure of the efficiency of the eye for three minutes of clear seeing at the time the test is taken. In applying the test to our problem, a record is taken at the beginning and at the close of work, and the ratios of the time clear and the time

[2] That there is practically no loss of sensitivity to brightness and color for this period of time was shown in our former paper by the results of our tests for brightness and color sensitivity with and without the time element as an aid to the test. (See also in connection with tests for brightness and color sensitivity, Ferree and Rand: A Note on the Determination of the Retina's Sensitivity to Colored Light in Terms of Radiometric Units, *Amer. Jour. of Psychol.*, 1912, Vol. XXIII, pp. 328-332; An Optics-Room and a Method of Standardizing its Illumination, *Psychol. Rev.*, 1912, Vol. XIX, pp. 364-373; Colored After-Image and Contrast Sensations from Stimuli in which no Color is Sensed, *ibid*, pp. 195-239; Rand: The Factors that Influence the Sensitivity of the Retina to Color: A Quantitative Study and Methods of Standardizing, *Psychol. Rev. Monog.*, 1913, 166 pp.; The Effect of Changes in the General Illumination of the Retina upon its Sensitivity to Color, *Psychol. Rev.*, 1912, Vol. XIX, pp. 463-490.

blurred are compared for the two cases to determine how much the eye has lost in efficiency as the result of work. Two values were used for the distance at which the test card was placed from the eye: (*a*) the maximal distance at which the test objects could be seen clearly in the momentary judgment, and (*b*) a distance less than this. The latter distance was finally chosen because for the maximal distance, towards the close of the test even when the eyes were fresh, the value of the time blurred became too high, it was found, to make the most effective comparison of the ratios obtaining at the beginning and at the close of work.

In order to eliminate the memory and fatigue factors which make it impossible to reproduce results in a series of tests with the same observer when the conventional Snellen test of visual acuity is employed, it will be remembered that the test card was made to consist of one or more simple objects, and the type of judgment was changed so that results were rendered in terms of clearness of vision instead of in terms of the ability to recognize a series of letters or characters.[3] That is, in this type of test the observer knows what the objects are, and he records the time during which he sees them clear and the time he sees them blurred. A number of test objects were used in the work of last year: two vertical parallel lines stamped 1 mm. apart on a white card ; the letters li printed in small type, the figures 

, etc. To these was added this year the figure 

This form of test object was suggested by the one used in Dr. Ives' visual acuity apparatus.[4] While apparently it gives ex-

[3] For a further explanation of this point see Tests for the Efficiency of the Eye under Different Systems of Lighting and a Preliminary Study of the Causes of Discomfort, TRANS. I. E. S., Vol. VIII, 1913, pp. 43-45.

[4] The writers wish to state that the test object used by them was similar to that employed by Dr. Ives only with regard to form. One of the prominent features of the apparatus used by Dr. Ives, for example, is a device for the control of the width of the parallel lines and the interspaces, while the figure used by us was printed on a white card with a fixed width of line and interspace. All that the writers wish to point out here is that a figure made up of parallel lines and interspaces is not, they believe, the most suitable for work of the kind we are doing because of the comparatively large mean variation it gives in the ratio, time clear to time blurred.

The figure was at first made 7 mm. in diameter; but this figure was found to be too large. It would blur irregularly over its surface, *i. e.*, the edges would become indistinct when the center was clear and *vice versa*. The figure finally adopted was 3.5 mm. in diameter. This size was found to be more satisfactory for our work.

cellent results for the purpose for which it was adopted by Dr. Ives, it gives too large a mean variation of ratio, time clear to time blurred, when the element of time is introduced into the visual acuity test to be of maximal service in our work. This is probably because a figure of this form is more influenced by adaptation, the streaming phenomenon,[5] and other variable physiological conditions of the retina than are, for example, the letters li. This latter object was found to be far the most satisfactory for our purpose. When used as test object the mean variation of the ratio, time clear to time blurred, for the same observer working under conditions as nearly constant as possible, is very small indeed.[6] Results will be given, therefore, in this report only for the work in which the letters li were used as test object.

In our work on distribution the tests were made in a room 30.5 ft. (9.29 m.) long, 22.3 ft. (6.797 m.) wide, and 9.5 ft. (2.895 m.) high. The artificial lighting was accomplished by means of two rows of fixtures of four fixtures each. Each row was 6 ft. (1.828 m.) from the side wall, and the fixtures were 6 ft. apart. The reflectors were 29 in. from the ceiling for the direct system, and 16 in. for the indirect and semi-indirect. Clear tungsten lamps were used as source. The voltage was kept constant by means of a voltmeter and a finely graduated wall rheostat placed in series with the lighting circuit.

In order to get the desired variation in the distribution of light and surface brightness in the field of vision required for the purposes of the test, four types of lighting were selected. One may be called a direct system; one an indirect system; one a semi-indirect system; and one was the illumination of a room by daylight. In case of the direct system, two bulbs making an angle of 180 deg. were used for each fixture. Directly above the

[5] Ferree, C. E., The Streaming Phenomenon, *Amer. Jour. of Psychol.*, 1908, 19, pp. 484-503; also The Intermittence of Minimal Visual Sensation, *Amer. Jour. of Psychol.*, 1908, Vol. XIX, pp. 112-130.

[6] The order of magnitude of the mean variation of the test for the fresh eye was obtained as follows. Beginning at 9 A. M., five three-minute records were run with a rest period of 20 minutes between each test. This was done with all observers on several days under each system of lighting employed. The rest period was taken in each case in a room lighted by daylight facing a wall with an evenly lighted mat surface. For a single series of five tests, the variations of the time seen clear in the three-minute period have always fallen within 1 per cent. for all of the observers we have used and all systems of lighting.

lights was fastened a slightly concaved porcelain reflector 16 in. in diameter. This type of fixture was not chosen with an especial reference to its representative character in any system of commercial classification. It was chosen rather with reference to the purpose of the test. It may be said, however, that it was the one in use throughout the building in which the tests were made and gives effects very similar to much of the lighting in actual use at the present time. In case of the indirect system, corrugated mirror reflectors were used enclosed in a brass bowl. For the semi-indirect system inverted alba reflectors 11 in. in diameter were employed. The daylight illumination came from three windows all on one side of the room. These windows were so sheltered that it was never possible for them to receive light directly from the sun or from a brilliantly illuminated sky. Moreover, the light from one of them, the one nearest the observer, was further diffused by passing through a diffusion sash made of double thick glass ground on one side.

In order to get the effect of the distribution factors on the eye's loss of efficiency as the result of a period of work, the tests should be conducted with the quality and intensity of light made as nearly equal as possible. The quality of light was made approximately the same for the three installations of artificial light by using clear tungsten lamps in each case. It was decided to make the intensity of light as nearly equal as possible at the point of test, and to give a supplementary specification of the lighting effects in the remainder of the room for the three installations of artificial light.[7] At the point of test the light was photometered in several directions. It was made approximately equal in the plane of the test card and as nearly as possible equal in the other directions.

The specification of the lighting effects in the remainder of the room has been accomplished as follows. (1) A determination

[7] We have not as yet made the fuller photometric specification of the room lighted by daylight with our present arrangement of windows, curtains, etc. We hope to make the effect of varying the distribution factors in daylight illumination (employing windows, skylights, etc.) the study of a future study. In this study a photometric analysis of the illumination effects produced will be made an especial feature.

has been made of the average illumination of the room under each of the three installations. The room was laid out in 3-ft. squares, and illumination measurements were made at 66 of the intersections of the sides of these squares. Readings were made in a plane 122 cm. above the floor with the receiving test-plate of the illuminometer in the horizontal, 45 deg. and 90 deg. positions, measuring respectively the vertical, 45 deg., and horizontal components. The 122 cm. plane was chosen because that was the height of the test object. (2) A determination was made of the brightness of prominent objects in the room, such as the test card, the reflectors for the semi-indirect installation, book of the observer, specular reflection from surfaces, etc. The brightness measurements were made by means of a Sharp-Millar illuminometer with the receiving test plate removed. The instrument was calibrated against a magnesium oxide surface obtained by depositing the oxide from the burning metal on a white card. By this method the reflecting surfaces were used as detached test plates. The readings were converted into candlepower per sq. in. by the following formula: Brightness $=$ Foot-candles/$\pi \times 144$. (3) Photographs were made of the room from three positions under each system of illumination.

In Fig. 1 (see "Further Experiments on the Efficiency of the Eye under Different Conditions of Lighting," TRANS. of the Ill. Eng. Soc., 1915, X, p. 452a)[8] the test room is drawn to scale: Plan of room, north, south, east, and west elevations.[9] In the drawing plan of room, are shown the 66 stations at which the illumination measurements were made and the position of the outlets for the lighting fixtures A, B, C, D, E, F, G, H. In the drawing, east elevation, the position of the observer at one of the points at

[8] The present paper is the second one in a series of three on the efficiency of the eye under different conditions of lighting. Before it was printed the third paper had been read at the eighth annual convention of the Illuminating Engineering Society and printed in the papers for that convention. In this paper it had been found necessary to repeat some of the data of the second paper for reference. Since both the second and third papers are now appearing simultaneously, the data that was repeated in the third paper has been omitted from the second. Wherever this has been done a cross reference is given to the third paper.

[9] For the scale drawing of the test-room, for the measurements for the direct and semi-indirect systems given in Table II, and for the photographs of the test-room, we are indebted to Mr. C. W. Jordan of the United Gas Improvement Co.

which the tests were taken is represented.[10] The other three positions are indicated by X.

Table I (see Table I, op. cit., p. 454) shows the number and wattage of the lamps used at outlets A, B, C, D, E, F, G, H; and Table II (see Table II, op. cit., 454-455) gives the illumination measurements for each of the 66 stations represented in Fig. 1, made with the receiving test plate of the photometer in the horizontal, vertical, and 45 deg. planes.

Table III has been compiled as a supplement to Table II for the purpose of making a comparative showing of the evenness of illumination at the 122 cm. level given by the three systems of lighting. Two cases may be made of this: (1) A comparison may be made of a given component from station to station; or (2) the difference between the components may be compared. To facilitate the comparisons, (*a*) the mean variation from the average of each of the components has been computed; and (*b*) the difference in the averages of the three components has been determined. Results for the first of these points are shown in Division A of the table; for the second in Division B.[11]

[10] The track along which the test card was moved was parallel to the east and west walls of the room. During the three hours of reading which intervened between the two tests the observer moved just far enough back from the upright supporting the mouthboard to give room for the book to be held and to permit of a comfortable reading position. The book was elevated and held approximately at an angle of 45 deg. When taking the test, the observer faced the north wall of the room, in such a position that with the eyes in the primary position, the lines of regard were parallel with the east and west walls of the room. Care was taken to have print of uniform size and distinctness for use with the three systems, and to have a page which gave a comparatively small amount of specular reflection. The brightness values of the page in the horizontal and 45 deg. positions for the three systems, are given in the legends for Figs. 8, 9, and 10.

[11] It would be interesting to make this comparison for other levels in the room and for a greater number of components. But unfortunately we have not been able to make the number of measurements needed for this comparison. The evenness of the illumination, it will be remembered, is not only of importance to the efficiency of the eye with reference to the object directly viewed, but also in its influence on the distribution of surface brightness. The evenness of surface brightness depends in general upon two sets of factors: (*a*) the nature and position of the reflecting surfaces in the room; and (*b*) the type of delivery of light to these surfaces.

We realize that the evenness of the illumination on the 122 cm. plane given by the indirect and semi-indirect units was somewhat interfered with by the reflectors of the direct system which were beneath and a little to the right of these units when in position for the test. Also the evenness of surface brightness on the ceiling for the direct system was interfered with by the indirect and semi-indirect reflectors, which were above and a little to the side of the direct units. The influence of this "dead apparatus" will be eliminated in the next series of installations. Moreover, the installation in each case was not such as to give the best effects obtainable from the type of reflector used. For example, the indirect reflectors were too close to the ceiling to give the maximum evenness of illumination and of surface brightness for the type of reflector used. The above analysis of effects is, therefore, not made for the purpose of drawing general conclusions with regard to the type of reflector employed. It is made solely for the sake of the comparison of the illuminating effects obtained with the corresponding results for loss of efficiency.

TABLE III.[12]—(Distribution Series).

Compiled from Table II to show a comparison of the evenness of the illumination at the 122 cm. level given by the direct, semi-indirect, and indirect systems. Division A shows the mean variation from the average for each of the three components of illumination; Division B, the difference in the average value of the three components.

Division A.

System	Mean variation of the components			Percentage of mean variation of components		
	Vertical	Horizontal	45°	Vertical	Horizontal	45°
Direct	1.88	1.09	1.53	38%	47%	32%
Semi-indirect ..	1.68	0.66	1.32	39%	42%	36%
Indirect	1.1	0.4	0.61	30%	37%	19%

Division B.

System	Difference between components			Percentage of difference between components		
	Vertical and Horizontal	Vertical and 45°	45° and Horizontal	Vertical and Horizontal	Vertical and 45°	45° and Horizontal
Direct	2.68	0.23	2.45	54%	5%	51%
Semi-indirect ..	2.68	0.64	2.04	63%	15%	56%
Indirect	2.13	0.31	1.82	59%	9%	55%

[12] For Tables I and II, see Tables I and II, Further Experiments on the Efficiency of the Eye, etc., Trans. I. E. S., 1915, Vol. X, pp. 454-455.

Fig. 2.—Showing the test room illuminated by the direct system. The photograph was taken from the south end of the room at a point 4 ft. from the west wall.

Fig. 3.—Showing the test room illuminated by the semi-indirect system. The photograph was taken from the south end of the room at a point 4 ft. from the west wall.

Fig. 4.—Showing the test room illuminated by the indirect system. The photograph was taken from the south end of the room at a point 4 ft. from the west wall.

Fig. 5.—Showing the illumination effects for the west wall of the room, direct system.

Fig. 6.—Showing the illumination for the west wall of the room, semi-indirect system.

Fig. 7.*—Showing the illumination effects for the west wall of the room, indirect system.

* For Figs. 8, 9, and 10, see Figs. 2, 3, and 4, "Further Experiments on the Efficiency of the Eye, etc." TRANS. of the I. E. S., 1915, Vol. X, pp. 452a-452b.

In Figs. 2 to 10 are given photographs showing the illumination of the room and the distribution of surface brightness for the three systems. Figs. 2, 3 and 4 are taken from the south end of the room at a point 4 ft. from the west wall. These photographs were taken so as to comprehend as much of the room as was possible in one view. They include the greater part of the ceiling, floor, and north wall; six of the fixtures; and about one-half of the east wall. The difference in surface brightness for the various points of the room (including the lighting units) is, it will be noted, greatest for the direct system, next greatest for the semi-indirect system, and least for the indirect system. The indirect and semi-indirect reflectors were attached to arms of approximately equal length which could be revolved about the fixture stem as an axis. When the tests were taken, these reflectors were turned in each case to the inside position indicated in the photograph, the object being to have the two types of reflectors as nearly as possible in the same position in the field of vision for the comparative tests. The direct fixtures, it will be noted, were below and slightly outside this position. In our next series of experiments, arrangements have been made such that the reflectors can be placed in exactly the same position for each type of installation when it suits the needs of the experiment to have it so. The slight deviation from exact coincidence found in these experiments is, however, perhaps of no great consequence for the purpose of the present work especially in the case of the indirect and semi-indirect reflectors. In Figs. 5, 6 and 7, are represented the illumination effects for the west half of the room. These photographs show the distribution of light and shade on the greater part of the west wall, and the adjacent ceiling, and include two of the fixtures. In Figs. 8, 9 and 10 (see Figs. 2-4, op. cit., pp. 452a-452b) are shown the brightness measurements of all surfaces having very high or very low brilliancy. The spot measured is indicated by a cross, and the numerical value of the brightness measurement in candlepower per square inch is printed nearby. These spots are also lettered for convenience of reference in the intensity series. That is, since several installations were used in the intensity series it was found convenient to express these values in tabular form and to identify them with the surfaces measured

by means of letters. These photographs were taken from a point in the line with the four positions of the observer as near to the south wall of the room as was possible, but owing to the narrow field of the camera as compared with the binocular field, these views include, for example, only about one-half of the field of vision of the observer at the test station nearest to this end of the room. The camera's field in this position corresponds in fact very closely to the field presented to the observer seated at the center of the room. While, therefore, not all of his field of view for all the positions at which tests were made is covered by the brightness measurements shown in the photographs, still the order of magnitude of brightness differences present in the field of vision for the different systems is well represented by these measurements, as can be seen by an inspection of the preceding photographs and from the descriptions of the installations used.

In order to facilitate certain features of comparison such as, for example, of the evenness of surface brightness for each system for all of the room, for all but the sources or the sources and spots above the sources, the brightness measurements shown in Figs. 8, 9 and 10 are also given in tabular form. These measurements and the letters identifying them with the surfaces measured are given in Table IV and V. (see Table III and IV, op. cit., p. 457). In making a comparison it should be noted that the spots measured are not in all cases identical for the three systems. That is, owing to the different effects produced by the different reflectors, the same spot was not always conspicuously light or dark for the three systems. The letters E, F, G, etc. may refer, then, to entirely different spots in case of the three systems.

In Tables VI and VII (see Table V and VI, op. cit., pp. 463-464) are shown some prominent ratios of surface brightness for the three systems.[13] In representing these ratios it has been consid-

[13] In attempting to make comparisons of the effect of the different magnitudes of brightness ratios, one obviously must bear in mind that the surfaces between which the ratios are established are not in all cases in the same position in the field of vision for the three systems. For example, the brightest surfaces in case of the indirect system, namely, the spots on the ceiling directly above the reflectors are farther removed from the direct line of vision of the observer when in the working position than were the brightest surfaces in case of the direct and semi-indirect systems. The position of the surface in the field of vision would come into question, for example, in making a determination of the maximum value of brightness difference that the eye is adapted to stand. While we have done a great deal

(*Continued on next page.*)

ered important to make a comparative showing for the three systems (*a*) of the extremes of surface brightness; and (*b*) of the relation of the brilliancy of objects in the surrounding field to the surface brightness at the point of work. The extremes of surface brightness are shown by giving the ratios between surfaces of the first, second, third, etc., order of brilliancy and the surface of the lowest order of brilliancy; and the comparison of the brilliancy of objects in the surrounding field to the brightness at the point of work by giving the ratios of the surfaces of the first, second, and third order of brilliancy to the brightness of the test card and the reading page in the working position. The following points may be noted. (1) The illumination effects produced by the direct system are characterized by great extremes of surface brightness and a high ratio of brilliancy of objects in the surrounding field to the surface brightness at the point of work. These effects are much less pronounced for the semi-indirect system, and still less for the indirect. (2) A comparison of this table with the tables showing loss of efficiency as the result of work shows that while the extremes of brightness are enormously larger for the direct than for the semi-indirect system, the eye loses almost as much in efficiency for three hours of work under the semi-indirect system as under the direct. That is, the greatest ratio of brightness for the direct system is over 1,000 times as much as the greatest ratio for the semi-indirect, while the difference in loss of efficiency for the two systems is comparatively insignificant. On the other hand the greatest ratio of brightness for the semi-indirect system is only about five times as much as for the indirect and the difference in loss of efficiency for three hours of work is very large, this loss of efficiency for three hours of work for the indirect system being, it will be noted,

of work on the effect of position of the brilliant surface in the field of vision in our investigation of the causes of discomfort, we have made no especial investigation of this point in relation to loss of efficiency. Doubtless what we shall all have to bear in mind is that even in the end we can not hope to specify narrowly what is most favorable, etc. in lighting conditions. The factors that enter into the concrete lighting situation are so complex, or rather are so variable and so rarely duplicated that we can hope to make general specifications with regard to what is most favorable, for example, only within very broad limits. If one wishes to work the conditions down to a finer point than this, the particular installation must itself be tested *in situ*. We are at present working on a shorter test which we hope will serve this purpose better than the test which has been used in the work described in this paper.

very small indeed. This seems to indicate (*a*) that for the scale of magnitudes present in this series of experiments, the gradation of surface brightness for the indirect system is very close to what the eye is prepared to stand without loss of efficiency; and (*b*) that an increase in differences in brightness above this point is followed at first by a rapid increase in loss of efficiency and later by a much slower increase. In the intensity series the following points also come out. (1) The effect of size of ratio on loss of efficiency is different for different orders of magnitude of brightness. That is, for the range of scale of magnitudes we have used, the lower is the order of magnitude, the greater is the ratio that is permissible. And (2) the size of the brilliant object as well as its brilliancy is of importance. That is, within certain limits, as yet undefined, an increase in the area of the brilliant surface causes an increase in loss of efficiency.

Supplementary to Tables IV–VII we have computed for the three systems the mean variation of the several brightness values from their average values. While important from the standpoint of showing the variation from the mean for the different systems, such a comparison is, however, probably not so important from the standpoint of the eye as are the comparisons given in Tables IV–VII. That is, from the standpoint of effect on the eye it is probably more important to give a representation of the brightness of individual surfaces, more especially of surfaces showing extremes of brightness, than it is the mean variation from the average brightness of all the surfaces. In order to make possible the comparison with and without the source and the spot above the source, the table is made to show separately the mean variation for the following measurements: (*a*) for all; (*b*) for all but the source; and (*c*) for all but the source and the spot above the source. Results are given in Table VIII.

Obviously the effect of these installations on the eye's ability to maintain its efficiency for a period of work will vary with the position of the observer in the room. The tests have been made, therefore, at four positions: one in which six fixtures were in the field of view, one in which four were in the field of view, one in which two were in the field of view, and one in which none were in the field of view. This variation of position at

which the observation was made accomplishes two purposes. (1) It gives us a more representative idea of the difference in the effect on the eye of the four types of lighting. And (2) it shows the effect of varying the number of surfaces showing brightness differences, particularly the number of primary sources in the field of view.

TABLE VIII.[14]—(DISTRIBUTION SERIES).

Compiled from Table IV to show the mean variations in surface brightness for the direct, semi-indirect, and indirect systems.[15]

Measurements considered	Mean variation for the three systems			Percentage of mean variation for the three systems		
	Direct	Semi-indirect	Indirect	Direct	Semi-indirect	Indirect
All	94.977	0.075	0.0235	189%	145%	135%
All but the source	0.0018	0.01817	0.0235	33%	120%	135%
All but the source and the spot above the source	0.0016	0.0013	0.0012	32%	30%	35%

[14] For Tables IV-VII, see Tables III-VI, Further Experiments on the Efficiency of the Eye, etc., TRANS. I. E. S., 1915, Vol. X, pp. 457, 463-464.

[15] It is scarcely necessary to point out that the above results seem to indicate that the great advantage of the indirect over the other systems of lighting we have used with regard to the factor: evenness of surface brightness, comes primarily at least from its provision for shielding the eye from the light source rather than from any conspicuously greater evenness of illumination given by it to the objects in the field of view. In fact all of the systems give a fairly even distribution of surface brightness outside of the source and the surfaces immediately surrounding it.

The need of keeping the surface brightness within certain limits and the primary importance of properly shielding the eye from the source to the accomplishment of this desideratum are both obvious Doubtless many ways will be devised in course of time for cutting down useless and harmful brightness differences in lighting effects. For example, the possibility is here suggested of producing a still smaller brightness difference than is given by the indirect reflectors of the type we have employed, by using semi-indirect reflectors of such a density as to give a surface brilliancy equal to that of the spot of light cast upon the ceiling. The value of this brilliancy, because of the larger area of luminous surface presented, could then be made smaller than that of the ceiling spot cast by the indirect reflector and still give the same amount of light to the room. A similar effect may be obtained with the indirect reflector by using lamps of lower wattage and adding the light needed to make up the deficiency by installing directly beneath the reflector lamps of low wattage in translucent enclosures of a density that will give a surface brilliancy equal to that of the ceiling spots. The effect of both of these devices would be to lower the surface brilliancy for a given light flux by increasing the area of the luminous surface. Whether either would be advisable from other standpoints we are not at present prepared to say.

Results will be given in this paper only for the position with six fixtures in the field of view. The results for the other positions will be given in a later paper. When working at the position with six fixtures in the field of view, our tests show that the eye loses practically nothing in efficiency as the result of three to four hours of work under daylight, it loses enormously for the same period of work under the direct installation, and almost as much under the semi-indirect installation. Under the indirect installation the eye loses a little more than under daylight, but not nearly so much as under the other installations.

The results of the work on distribution are given in Tables IX and X. Early in the work it was found that nearly as much difference in result was gotten for two as for three hours of work. In Table IX is shown the loss in efficiency for Observer R for three hours of work under the four systems; and in Table X, the loss in efficiency for Observer G for two hours of work. These tables are typical of the results obtained from all of our observers for these periods of work.[16] Column 1 of these tables gives the type of lighting system. Column 2 gives the total wattage of the lamps used, and Column 3 the voltage at which these lamps were operated. Columns 4, 5, and 6 give the foot-candles of illumination at the point of work measured respectively in the horizontal, vertical, and 45 deg. planes. Column 7 gives the maximal distance at which the test object could be seen clearly, and Column 8 the distance chosen at which to conduct the test for loss of efficiency. Care was taken in every case to choose this working distance of such a value that the ratio it sustained to the maximum distance was always approximately the same. Column 9 gives the total time the test object was seen clear in the three minutes of observation and Column 10 the total time it was seen blurred. Column 11 gives the ratio of the total time seen clear to the total time seen blurred, and Column 12 gives the comparative values of these ratios in terms of a common standard. These ratios were reduced to a common scale or standard in order to make the comparison of the amounts of

[16] Obviously in the consideration of the effect of a given lighting system on the ability of the eye to hold its efficiency for a period of work, the age of the observer and the condition of his eyes should be taken into account. For a full clinic report of the eyes of the observers employed, see op. cit., foot-note 14, p. 460.

change in their ratios easier. They express the comparative ability of the eye to sustain its power of clear seeing for three minutes before and after work for the four conditions of lighting used.

It will also be noted from Column 8 of the above tables that the visual acuity tests show that acuity of vision as determined by the momentary judgment is higher for the same foot-candles of illumination under daylight than under artificial light, and of the artificial lights it is very slightly highest for the indirect system, next highest for the semi-indirect system, and slightly lowest for the direct. It will thus be seen that for all the purposes of clear seeing, whether the criterion be maximal acuity or the ability of the eye to hold its efficiency for a period of work, the best results are given in order by the systems that give the best distribution. The effect of distribution, however, on the ability of the fresh eye to see clearly, is not nearly so great as it is on its power to hold its efficiency for a period of work.

In order to give a typical representation in graphic form of the effect on the efficiency of the eye of a period of work under these four conditions of lighting, the results of the above tables will also be given in the form of a chart made up of straight lines showing in each case the loss of efficiency from beginning to close of work. In constructing these charts, the length of time of work is plotted along the abscissa, and the ratio of the time the test object is seen clear to the time it is seen blurred is plotted along the ordinate. Each one of the large squares along the abscissa represents one hour of work and along the ordinate an integer of the ratio. Chart A shows the results for Table IX, and Chart B for Table X. An inspection of these charts will show how widely different in amount is the loss in efficiency under the specified conditions for the direct and semi-indirect systems as compared with the indirect system and daylight, and how close is the correspondence between the results for the direct and semi-indirect system, and between the results for the indirect system and daylight.

The loss in efficiency found in the above work seems to be predominantly, if not entirely, muscular, for the tests for the sensitivity of the retina show practically no loss in sensitivity

TABLE IX.—(DISTRIBUTION SERIES).

Observer R, showing the eye's loss in efficiency as the result of 3 hours of work under the systems of indirect, semi-indirect, and direct lighting employed as compared with daylight. 8 lamps, indirect and semi-indirect systems; 16 lamps, direct system. Intensities equalized on test card. Clear tungsten lamps.

Lighting system	Watts	Volts	Foot-candles			Time	Maximal distance at which test object can be seen clear	Working distance	Total time clear	Total time blurred	Total time clear ÷ total time blurred	Ratios reduced to common standard
			Horizontal	Vertical	45°							
Daylight	—	—	5.5	1.32	4.2	9 A.M.	90.0	74.0	137	43	3.18	3.5
						12 M.	90.0	74.0	135	45	3.0	3.3
Indirect	800	107	5.2	1.36	3.5	9 A.M.	84.5	67.5	135	45	3.0	3.5
						12 M.	84.5	67.5	132	48	2.75	3.2
Semi-indirect	760	107	5.8	1.45	4.0	9 A.M.	80.5	68.5	142	38	3.73	3.5
						12 M.	79.5	68.5	92	88	1.04	0.97
Direct	880	107	4.2	1.41	2.6	9 A.M.	81.0	68.0	139	41	3.39	3.5
						12 M.	78.0	68.0	71	109	0.65	0.67

TABLE X.—(DISTRIBUTION SERIES).

Observer G, showing the eye's loss in efficiency as the result of 2 hours of work under the systems of indirect, semi-indirect, and direct lighting employed as compared with daylight. 8 lamps, indirect, and semi-indirect systems; 16 lamps, direct system. Intensities equalized on the test card. Clear tungsten lamps.

Daylight	—	—	5.5	1.32	4.2	9 A.M.	91.0	77.0	161	19	8.45	3.50
						11 A.M.	91.0	77.0	160	20	8.00	3.31
Indirect	800	107	5.2	1.36	3.5	9 A.M.	85.0	72.0	159	21	7.57	3.50
						11 A.M.	85.0	72.0	157	23	6.83	3.15
Semi-indirect	760	107	5.8	1.45	4.0	9 A.M.	83.0	72.0	159	21	7.55	3.50
						11 A.M.	81.0	72.0	150	30	5.00	2.30
Direct	880	107	4.2	1.41	2.6	9 A.M.	81.0	69.5	145	35	4.14	3.50
						11 A.M.	78.0	69.5	131	49	2.67	2.20

Chart A (Observer R).—Showing the eye's loss in efficiency as the result of three hours of work under the systems of indirect, semi-indirect and direct lighting employed as compared with daylight.

Lighting system	Watts	Volts	Foot-candles Horizontal	Foot-candles Vertical	45°
A—Daylight	—	—	5.5	1.32	4.2
B—Indirect	800	107	5.2	1.36	3.5
C—Semi-indirect ...	760	107	5.8	1.45	4.0
D—Direct	880	107	4.2	1.41	2.6

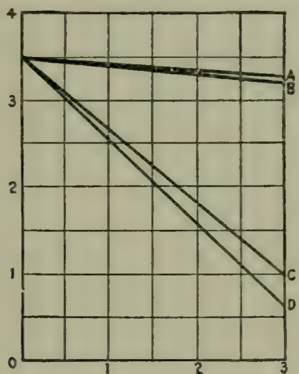


Chart A.

Chart B (Observer G).—Shows the eye's loss in efficiency as the result of two hours of work under the systems of indirect, semi-indirect and direct lighting employed as compared with daylight.

Lighting system	Watts	Volts	Foot-candles Horizontal	Foot-candles Vertical	45°
A—Daylight........	—	—	5.5	1.32	4.2
B—Indirect	800	107	5 2	1.36	3.5
C—Semi-indirect ...	760	107	5.8	1.45	4.0
D—Direct	880	107	4.2	1.41	2.6

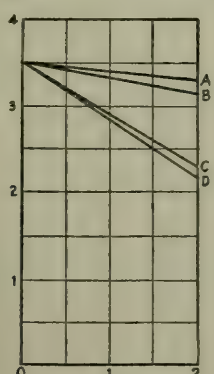


Chart B.

as the result of work under any of the installations employed.[17] The following reasons are suggested why the muscles of the eye giving both fixation and accommodation should be subjected to a greater strain by the direct and semi-indirect installations than by the indirect installation or daylight. (1) The bright images of the sources falling on the peripheral retina, which is in a perpetual state of darkness-adaptation as compared with the central retina, and is, therefore, extremely sensitive in its reaction to such intensive stimuli, set up a reflex tendency for the eye to fixate them instead of, for example, the letters which the observer is required to read. (2) Likewise a strong reflex tendency to accommodate for these brilliant sources of light, all at different distances from each other and the lettered page, is set up. (3) These brilliant images, falling on a part of the retina that is not adapted to them, causing as they do acute discomfort in a very short period of time, doubtless induce spasmodic contractions of the muscles which both disturb the clearness of vision and greatly accentuate the fatiguing of the muscles. The net result of all these causes is excessive strain which shows itself in a loss of power to do work. In the illumination of a room by daylight, however, with a proper distribution of windows, the situation is quite different. The field of vision contains no bright sources of light to disturb fixation and accommodation and to cause spasmodic muscular disturbances due to the action of the intensive light sources on the dark-adapted and sensitive peripheral retina. As we have already pointed out, the light waves have suffered innumerable reflections and the light has become diffuse. The field of vision is, comparatively speaking, uniformly illuminated, and there are no extremes of surface brightness. The illumination of the retina, therefore, falls off more or less gradually from center to periphery, as it should to permit of fixation and accommodation for a given object with a minimum amount of strain.

[17] In the next paper of the series it is shown (see op. cit. pp. 484-490) that the loss in muscular efficiency is confined largely to the accommodation muscles. The fixation muscles apparently suffer little loss for the period of work we have used.

III. THE EFFECT OF VARIATION IN THE INTENSITY OF LIGHT ON THE EFFICIENCY OF THE EYE FOR A PERIOD OF WORK.

It is not our purpose, however, to contend that distribution of light and surface brightness in the field of vision is the only factor of importance in the illumination of a room. The intensity and quality of light must also be taken into account. For example, one of the most persistent questions asked by the illuminating engineer is: "How much light should be used with a given lighting installation to give the best results for seeing?"

We have undertaken, therefore, to determine the most favorable range of intensity for the four types of lighting we have used. Our work shows in general the following results. A very wide range of intensity is permissible for daylight, and a comparatively wide range for the indirect installation. For the semi-indirect installation the eye fell off heavily in efficiency for all intensities with exception of a narrow range on either side of 2.2 foot-candles measured at the level of the eye at the point of work with the receiving surface of the photometer in the horizontal plane. For the direct installation no intensity could be found for which the eye did not lose a very great deal in efficiency as the result of work. Thus it seems that the factors we have grouped under the heading distribution are fundamental. That is, if the light is well distributed and diffuse, as it was in case of the daylight and indirect installations we used, and there are no extremes of surface brightness, the ability of the eye to hold its efficiency is, within limits, independent of intensity. In short, the retina is itself highly accommodative or adaptive to intensity, and if there is the proper distribution and diffuseness of light and the proper gradation of surface brightness in the field of vision, the conditions are not present which cause strain and consequent loss in efficiency in the adjustment of the eye. The results of this series of tests, then, accomplish two purposes. (1) They show that when the distribution and diffuseness of light and the distribution of surface brightness in the field of view are properly taken care of, the eye, so far as the problem of lighting is concerned, is practically independent of intensity. And (2) they show the effect on the efficiency of the eye of the variations in surface brightness pro-

duced by varying intensity in case of the direct and semi-indirect installations we have used.

The tests were made in the same room, with the same fixtures, and in general with the same conditions of installation and methods of working as were described in the work on distribution. To secure the various degrees of intensity needed, lamps of different wattage were used. These were selected from a series of tungsten lamps ranging from 15–100 watts. In order to keep the distribution factor as nearly constant as possible for a given type of system, the lamps used in making the test for that type of system were all of one wattage, *i. e.*, all 15's, 25's, 40's, 60's, or 100's.

For the semi-indirect system the total range of intensity of illumination employed is shown by the following figures. The series was begun with 25-watt lamps[18] and consisted of 25, 40, 60, and 100-watt lamps.[19] For the 25-watt lamps the photometer reading at the point of work with the receiving test plate of the photometer in the horizontal plane, showed 1.6 foot-candles; with the test plate in the vertical position 0.45 foot-candle; in the 45 deg. position 1.15 foot-candles. For the 100-watt lamps, 6.8 foot-candles were obtained with the test plate horizontal; 1.82 foot-candles with the test plate vertical; and 4.5 foot-candles with it in the 45 deg. position. The tests for loss in efficiency[20] showed that the intensity most favorable to the eye was secured

[18] Since the most favorable intensity was given by the 40-watt lamps and since the 15-watt lamps gave so little light as to be extremely trying to the eyes, it was thought best to begin the series with the 25-watt lamps instead of the 15 as was done in case of the direct system.

[19] Owing to their smaller size, socket extenders had to be used for the 25 and 40-watt lamps. That is, without the extenders these lamps came so low in the reflector as to change the distribution effects given by the reflector.

[20] In conducting these tests it was found necessary to allow a period of adaptation without work to the illumination of the room before the first test was taken. If this were not done, especially in case of the lower intensities of light used, the changing sensitivity of the eye to the intensity of light employed produced a noticeable change in the visual acuity between the times the tests before and after work were taken. Since the distance of the test card was kept the same for the two tests, this change in the visual acuity tended to influence the ratio: time clear to time blurred. To determine the length of time needed with a given intensity of light to insure a constant acuity so far as adaptation is concerned, preliminary tests were made as follows. The acuity of the observer was taken every three minutes until no noticeable change was found. This length of time was then always allowed for that observer as an adaptation period prior to the loss of efficiency test conducted for the intensity of illumination.

when the photometric reading with the test plate in the horizontal plane showed 2.2 foot-candles; in the vertical plane, 0.58 foot-candle; and in the 45 deg. plane, 1.52 foot-candles. The total wattage in this case was only 320. At this intensity of illumination the semi-indirect installation, so far as its effect on the eye is concerned, compares very favorably with the indirect installation at such ranges of intensity as we have employed. At intensities appreciable higher than this most favorable value, however, or appreciably lower, the loss in efficiency is very great. At the intensity commonly recommended in lighting practise, this semi-indirect installation is almost, if not quite as damaging as the direct installation. The intensity recommended by the Illuminating Engineering Society, for example, in its primer issued in 1912, ranges from 2-3 to 7-10 foot-candles, depending upon the kind of work; 5 foot-candles is taken as a medium value. This medium value is more than double the amount we have found to give the least loss in efficiency for the type and installation of semi-indirect lighting we have used. The intensity we have found to give the least loss in efficiency for this type of lighting does not, however, give maximal acuity of vision as determined by the momentary judgment. At an intensity that does give maximal acuity of vision as determined by the momentary judgment, the eye runs down rapidly in efficiency. That is, in this type of lighting one or the other of these features must be sacrificed. High acuity and little loss in efficiency can not both be had at the same intensity. These features can both be had only under daylight and, in case of the installations, we used, with the indirect system. However, the amount of light we find to give the least loss in efficiency seems to be sufficient for much of the work ordinarily done in the office or home. It is not enough, though, for drafting or other work requiring great clearness of detail. By giving better distribution effects this system is supposed also to be a concession to the welfare of the eye, but our tests show that this concession is not so great as it is supposed to be. In fact, installed at the intensity of illumination ordinarily used, or at an intensity great enough for all kinds of work, little advantage is gained for the eye in this type of lighting with reflectors of low or medium densities; for with these

intensities of light and densities of reflector, the brightness of the source has not been sufficiently reduced to give much relief to the suffering eye. Until this is done in home, office, and public lighting, we can not hope to get rid of eye strain with its complex train of mental and physical disturbances. If the semi-indirect principle of lighting is to be used with benefit to the eye, a density of reflector and type of installation must be employed that will give a gradation of brightness in the field of view in conformity with the limits of difference that the eye can stand without loss in efficiency or comfort.

In case of the direct system of lighting, we were able to improve the conditions so far as loss of efficiency of the eye is concerned, by reducing the intensity; but this system never proved to be so favorable in this regard as even the semi-indirect system. In the tests made under the direct system care was taken to have the fixtures as nearly as possible in the same position as they were for the semi-indirect system. Our fixtures for the direct system were so installed that either one or two lamps could be used in each fixture, totalling respectively 8 and 16. In order to get a wider range of intensity both numbers of lamps were used, *i. e.,* one series was made with 8 lamps and aonther with 16. Four intensities of light were used in each case. These intensities were secured in the 8-lamp system by using lamps totalling 120, 200, 320, and 480 watts. The foot-candles at the point of work ranged from 0.64 with the receiving test plate of the photometer in the horizontal, 0.32 in the vertical, and 0.49 in the 45 deg. position with the lamps totalling 120 watts, to 2.6 with the test plate in the horizontal, 1.02 in the vertical, and 2.0 in the 45 deg. position with the lamps totalling 480 watts. The four intensities were secured in the 16-lamp system by using lamps totalling 240, 365, 400, and 880 watts. The foot-candles at the point of work with the 16-lamp system ranged from 1.23 with the test plate in the horizontal, 0.54 in the vertical, and 0.935 in the 45 deg. position with the lamps totalling 240 wattts, to 4.2 with the test plate in the horizontal, 1.41 in the vertical, and 2.6 in the 45 deg. position with the lamps totalling 880 watts. The most favorable intensity was secured by an installation that gave 1.16 foot-candles with the test plate in the horizontal, 0.45 in the

vertical, and 0.85 in the 45 deg. position. This intensity was given by the 8-lamp system with a total wattage of 200. At this intensity, however, the loss in the efficiency of the eye for three hours of work was almost four and one-half times as great as for the most favorable intensity for the semi-indirect system; and more than four and one-half times as great as for a wide range of intensities for either the indirect system or daylight.

The following specification was made of the illumination effects for the intensity series. (1) Illumination measurements were made for the highest intensity employed at the 66 stations in the test room. These measurements were made in the way described in the preceding section. For the other intensities employed, measurements were made at 9 representative stations to show in a general way the order of magnitude of reduction produced by using the lamps of lower wattages. (2) Brightness measurements were made of prominent objects in the room, such as the test card, the book of the observer, and all surfaces showing very high or very low brilliancy, for all intensities for all systems.

In Table XI are given the illumination measurements for the highest wattages used made with the receiving test plate of the photometer in the horizontal, vertical, and 45 deg. planes. Tables XII, XIII and XIV show the illumination measurements for the other wattages employed in the series at nine representative stations. These measurements are intended to show the order of magnitude of reduction of the illumination of the room produced by using the lamps of lower wattage. They conform in each case pretty closely, it will be noted, to the simple ratio of the wattages employed. Tables XV, XVI and XVII give the brightness measurements for these installations for the different intensities used. The points at which the measurements were taken are indicated by the letters A, B, C, D, E, F, etc., see Figs. 8 and 9. In Tables XVIII, XIX and XX are given the prominent brightness ratios for the different intensities used. It was stated in the preceding section that the order of magnitude of the brightness scale exerts an influence on the effect of brightness ratio on the eye's loss of efficiency. This influence is readily seen on comparing the results of Table XVIII with those of

Table XXI. That is, while the various brightness ratios remain pretty much the same for the different intensities of light employed, the least loss of efficiency was given by the 40-watt lamps. This loss was, for example, very much less than was given by the 100-watt lamps, not quite so much less than was given by the 60-watt lamps, and very little less than was given by the 25 watt lamps. The loss in efficiency for the 25-watt lamps can also doubtless be attributed in part to an insufficient amount of light. At least the testimony of the various observers was that not enough light was given by these lamps for ease and comfort in reading. The results of these experiments seem to show, then, that a given order of magnitude of brightness difference in the field of view has more effect on the efficiency of the eye when the general scale of brightness values is higher than when it is low.

A comparison of Tables XIX and XX with Tables XXII and XXIII shows the influence of the area of the bright surface on the ability of the eye to hold its efficiency for a period of work. For example, although it is shown in Table XIX that the ratios: lightest surface to darkest surface, and lightest surface to test card and reading page, are greater in the 16-lamp system for the 15 than for the 25-watt lamps, Table XXII shows that greater loss of efficiency is caused by the 25-watt lamps. Similarly, Table XX shows that in the 8-lamp system these ratios are greater for the 25 and 40 than for the 60-watt lamps, while Table XXIII shows that the 60-watt lamps cause the greater loss in efficiency. This may be explained as follows. The brightest surfaces in the field of vision for the direct system are the filaments of the lamps. The brightness measurements given in the table are in terms of candlepower per square inch. The candlepower per square inch is the same, for example, for the filaments of the 15 as for those of the 25-watt lamps. But since the darkest surfaces, the test card, and the reading page, are darker for the 15-watt than for the 25-watt system, the ratios: lightest to darkest surface, lightest surface to test card, and lightest surface to reading page, are greater for the 15 than for the 25-watt system. While, however, the candlepower per square inch is the same for the 15 as for the 25-watt filaments, the actual candle-

power is less for the 15-watt filaments because of their smaller area of surface. That is, the area of the brilliant surface or in terms of luminous effects, its actual candlepower must be taken into account in estimating the effect on the eye as well as the candlepower per square inch. The effect of area on sensation is well known in physiological optics (for example, see Abney, Philos. TRANS., 1897, CXC, A, p. 169), and is expressed in the law that within limits an increase of area of the stimulus functions as an increase of intensity, although not in a simple ratio. Apparently, too, in its effect on the eye's power to maintain its efficiency for a period of work, an increase of area of the brilliant surface also functions within limits as an increase in intensity.[21] Ratios expressed in candlepower per square inch do not seem therefore, in all cases to be an adequate specification of surface brightness, so far as its effect on the efficiency of the eye is concerned, unless the areas compared be the same.

[21] The above explanation is, however, not complete. It shows only that the ratios: lightest to darkest surface, and lightest surface to test card and reading page, are greater for the 15 than for the 25-watt lamps because the candlepower per square inch not the actual candlepower was used in computing the ratios.

We are not at present able to give the ratio of actual candlepower of lightest to darkest, lightest to reading page, etc., because we did not measure the actual candlepower of the darkest surface, the reading page, etc., only the candlepower per square inch. However, since the test card and the reading page were of the same area in case of the different intensities, and the darkest surface of approximately the same area, ratios based on the total candlepower of the lightest surface (the lamp filament) and the candlepower per square inch of the darkest surface, test card, and reading page have comparative values. These ratios are very little different for the 15- and 25-watt lamps. That is, the ratio lightest to darkest for the 15-watt lamps = 28,698, for the 25-watt lamps = 28,933; lightest to test card for the 15-watt lamps = 11,828, for the 25-watt lamps = 12,616; lightest to reading page for the 15-watt lamps = 7,352; for the 25-watt lamps = 7,483.

A complete explanation of the result will doubtless involve two factors (1) the ratio of the actual candlepower of the lightest and darkest surfaces; and (2) the point brought out in connection with Tables XVIII and XXI, namely that a given order of magnitude of brightness difference in the field of view has more effect on the loss of efficiency of the eye when the general scale of brightness values is high than when it is low. From this we would expect, for example, that if the ratio lightest to darkest surface and lightest surface to test card and reading page were equal or approximately so for the 25- and 15-watt lamps, for example, the greater loss of efficiency should come with the lamps of higher wattage. Similarly for the 8-lamp system, the 60- and 40-watt lamps should cause a greater loss of efficiency than the 25-watt lamps. The 15-watt lamps with this system gave too little light to read with ease and comfort hence are ruled out of count in the comparison.

For investigating in detail the effect of area of the brilliant surface on the eye's loss of efficiency, the campimeter may prove of convenience and of service. This is one of the instances where the abstract may be used to advantage to supplement the concrete method of investigation. (See Memorandum on the Report of the Research Committee, TRANS. I. E. S., 1914, Vol. IX, No. 4, p. 358.)

The great difficulty with the abstract type of investigation, as the writers see the case at this time, is that a determination of what is permissible with regard to one factor in isolation may not be at all permissible in conjunction with other factors. A more feasible plan seems to us to be to vary the factor over a certain practical range in an actual concrete situation. By a proper selection of the concrete situations employed the ground of all that is practicable in lighting can be covered, and the results obtained can have a safe application.

TABLE XI.—(INTENSITY SERIES.)

Showing the illumination measurements in foot-candles at each of the 66 stations represented in Fig. 1 for the highest wattage used in the intensity series for the semi-indirect system, and the direct system (16 lamps and 8 lamps).

	Horizontal			Vertical			45°		
Station	Semi-indirect 800 watts	Direct (8 lamps) 480 watts	Direct (16 lamps) 400 watts	Semi-indirect 800 watts	Direct (8 lamps) 480 watts	Direct (16 lamps) 400 watts	Semi-indirect 800 watts	Direct (8 lamps) 480 watts	Direct (16 lamps) 400 watts
1	1.74	1.17	0.75	—	—	—	—	—	—
2	1.86	1.10	0.63	—	—	—	—	—	—
3	1.80	1.33	0.76	—	—	—	—	—	—
4	1.66	0.91	0.76	—	—	—	—	—	—
5	2.68	1.50	1.40	—	—	—	—	—	—
6	4.00	1.90	1.25	—	—	—	—	—	—
7	4.40	2.10	1.20	—	—	—	—	—	—
8	3.80	3.30	1.90	—	—	—	—	—	—
9	2.85	2.20	1.25	—	—	—	—	—	—
10	1.86	1.12	0.70	—	—	—	—	—	—
11	1.88	1.42	0.90	—	—	—	—	—	—
12	2.90	2.80	2.60	0.55	0.45	0.44	1.00	1.70	1.42
13	5.50	5.00	3.40	0.67	0.40	0.41	2.85	3.00	1.75
14	6.80	2.60	1.70	0.74	0.49	0.45	3.40	1.50	0.98
15	6.80	2.25	1.73	0.74	0.50	0.41	3.40	1.18	0.92
16	6.80	4.40	4.00	0.69	0.41	0.41	3.60	2.40	2.40
17	3.50	2.60	2.40	0.67	0.41	0.45	1.74	1.48	1.80
18	2.00	1.10	1.10	0.60	0.47	0.48	1.11	0.63	0.67
19	2.95	1.39	1.40	1.14	0.67	0.70	1.94	1.00	1.12
20	4.50	2.40	2.50	1.13	0.80	0.92	3.80	1.60	1.75
21	7.00	3.80	3.00	1.60	1.18	1.20	4.30	2.40	2.24
22	6.70	2.40	1.90	1.48	0.83	0.66	4.10	1.54	1.28
23	6.60	3.00	2.00	1.50	1.01	0.75	4.35	2.10	1.30
24	6.40	5.00	2.90	1.62	1.67	1.00	4.20	3.35	2.00

TABLE XI.—(INTENSITY SERIES.)—(*Continued*).

	Horizontal			Vertical			45°		
Station	Semi-indirect 800 watts	Direct (8 lamps) 480 watts	Direct (16 lamps) 400 watts	Semi-indirect 800 watts	Direct (8 lamps) 480 watts	Direct (16 lamps) 400 watts	Semi-indirect 800 watts	Direct (8 lamps) 480 watts	Direct (16 lamps) 400 watts
25	4.20	2.80	2.30	1.40	1.15	0.82	2.50	2.00	1.45
26	2.23	1.46	1.10		—	—	—	—	—
27	2.45	1.42	1.20	—	—	—	—	—	—
28	3.95	2.80	2.20	1.54	1.22	0.83	3.10	2.30	1.82
29	6.80	5.80	4.10	1.82	1.48	1.00	4.30	4.20	2.82
30	6.70	3.20	1.70	1.78	1.11	0.75	5.10	2.50	1.40
31	7.40	2.85	2.10	2.20	1.06	0.81	5.20	2.35	1.60
32	7.10	5.15	4.00	2.10	1.18	1.20	5.20	3.80	2.90
33	4.10	3.50	2.40	1.75	1.05	0.98	3.20	2.70	2.05
34	4.60	2.65	2.35	1.76	1.35	1.41	3.40	2.20	2.10
35	6.80	4.00	3.10	2.40	2.00	1.44	5.20	3.30	2.50
36	6.40	3.60	2.00	2.45	1.61	1.00	4.70	2.50	1.68
37	6.20	3.20	1.70	2.48	1.64	0.95	4.75	2.70	1.42
38	7.00	4.30	3.20	2.52	2.15	1.50	5.40	3.50	2.40
39	4.40	3.00	2.70	1.95	1.50	1.44	3.68	2.60	2.20
40	2.37	1.26	1.10	—	—	—	—	—	—
41	1.70	1.43	0.95	—	—	—	—	—	—
42	3.30	2.70	2.40	2.00	1.42	1.15	3.30	2.40	2.25
43	7.00	4.90	3.60	2.38	1.87	1.17	5.62	4.10	3.00
44	7.10	3.70	2.00	2.88	1.48	1.00	5.78	2.65	2.00
45	6.80	3.60	2.05	2.65	1.54	1.15	5.60	2.35	2.10
46	7.10	4.70	4.00	2.58	1.45	1.20	5.40	3.70	2.95
47	3.65	2.50	2.45	1.82	1.24	1.17	3.20	2.30	2.20
48	3.70	2.60	2.50	1.92	1.45	1.50	3.50	2.15	1.80
49	6.20	3.60	3.00	2.45	2.10	1.60	5.00	3.10	2.18
50	6.00	2.50	2.00	2.70	1.80	1.24	5.20	2.55	1.85

TABLE XI.—(INTENSITY SERIES.)—(*Continued*).

	Horizontal			Vertical			45°		
Station	Semi-indirect 800 watts	Direct (8 lamps) 480 watts	Direct (16 lamps) 400 watts	Semi-indirect 800 watts	Direct (8 lamps) 480 watts	Direct (16 lamps) 400 watts	Semi-indirect 800 watts	Direct (8 lamps) 480 watts	Direct (16 lamps) 400 watts
51	5.50	2.50	1.90	2.52	1.78	1.26	5.10	2.50	1.90
52	4.85	3.60	3.10	2.55	2.10	1.60	4.65	3.30	2.75
53	3.20	2.30	2.30	1.73	1.54	1.26	3.10	2.25	1.92
54	2.47	3.00	4.00	1.77	1.80	2.10	2.65	3.10	3.20
55	4.70	4.00	3.55	2.28	1.68	1.30	4.35	3.80	2.80
56	5.40	2.10	1.90	2.98	1.82	1.25	5.60	2.50	2.10
57	5.10	2.30	1.67	2.95	1.74	1.35	5.30	2.60	2.15
58	5.20	4.40	4.30	2 60	1.69	1.88	5.28	3.60	3.35
59	2.90	2.45	2.50	2.35	1.38	1.20	3.60	2.50	2.22
60	2.52	1.94	1.70	1.82	1.49	1.37	2.72	2.35	2.51
61	3.92	2.20	2.08	2.90	2.25	1.80	4.80	3.40	2.70
62	3.52	1.64	1.47	2.87	1.86	1.50	4.70	2.35	1.96
63	3.42	1.66	1.40	2.62	1.86	1.40	4.30	2.40	1.96
64	3.32	2.10	2.20	2.37	2.20	1.72	4.10	3.10	3.00
65	2.30	1.43	1.62	1.66	1.74	1.38	3.00	2.35	2.25
66	1.40	0.90	0.97	—	—	—	—	—	—
Average	4.44	2.72	2.14	1.93	1.48	1.12	4.03	2.55	2.06

TABLE XII.—(INTENSITY SERIES.)

Showing the illumination measurements in foot-candles at nine representative stations for the different intensities used for the semi-indirect system.

Station	Horizontal				Vertical				45°			
	800 watts	480 watts	320 watts	200 watts	800 watts	480 watts	320 watts	200 watts	800 watts	480 watts	320 watts	200 watts
Card	6.8	3.3	2.2	1.6	1.82	0.94	0.58	0.45	4.5	2.4	1.52	1.15
12	2.9	1.79	1.0	0.75	0.55	0.35	0.22	0.17	1.49	0.76	0.51	0.4
16	6.8	3.2	2.0	1.32	0.69	0.44	0.23	0.15	3.6	1.75	1.03	0.68
31	7.4	3.6	2.2	1.6	2.2	0.94	0.58	0.44	5.2	2.4	1.53	1.15
34	4.6	2.1	1.45	0.95	1.76	0.9	0.58	0.43	3.4	1.68	1.12	0.74
39	4.4	1.79	1.17	0.93	1.95	0.86	0.54	0.41	3.68	1.52	0.95	0.73
45	6.8	3.3	2.2	1.4	2.65	1.3	0.82	0.58	5.6	2.7	1.7	1.19
54	2.47	1.31	0.87	0.7	1.77	1.15	0.62	0.48	2.65	1.47	0.95	0.76
58	5.2	2.82	1.9	1.44	2.6	1.35	0.87	0.63	5.28	2.68	1.8	1.3
Average	4.44	2.66	1.78	1.11	1.93	1.16	0.77	0.48	4.03	2.42	1.61	1.01

TABLE XIII.—(INTENSITY SERIES.)

Showing the illumination measurements in foot-candles at nine representative stations for the different intensities used for the direct system (16 lamps).

Station	Horizontal			Vertical			45°		
	400 watts	365 watts	240 watts	400 watts	365 watts	240 watts	400 watts	365 watts	240 watts
Card	1.86	2.1	1.23	0.8	0.6	0.54	1.46	1.33	0.935
12	2.6	1.45	1.43	0.44	0.275	0.265	1.42	0.68	0.85
16	4.0	4.4	2.6	0.47	0.34	0.385	2.4	2.4	1.55
31	2.1	2.1	1.45	0.81	0.735	0.575	1.6	1.68	1.1
34	2.35	2.3	1.84	1.41	1.49	1.08	2.1	2.5	1.57
39	2.7	2.6	1.5	1.44	1.55	0.825	2.2	2.4	1.19
45	2.2	1.75	1.45	1.27	1.3	0.77	2.1	1.95	1.23
54	4.0	1.6	1.34	2.1	1.13	0.78	3.2	1.64	1.38
58	4.3	2.3	2.5	1.88	1.25	1.02	3.35	2.1	2.1
Average	2.14	—	1.26	1.12	—	0.67	2.06	—	1.21

TABLE XIV.—(INTENSITY SERIES.)

Showing the illumination measurements in foot-candles at nine representative stations for the different intensities used for the direct system (8 lamps).

Station	Horizontal				Vertical				45°			
	480 watts	320 watts	200 watts	120 watts	480 watts	320 watts	200 watts	120 watts	480 watts	320 watts	200 watts	120 watts
Card	2.6	1.97	16	0.64	1.02	0.65	0.45	0.32	2.0	1.39	0.85	0 45
12	2.8	1.94	.36	0.69	0.45	0.41	0.21	0.15	1.7	1.12	0.76	0.41
16	4.4	2.8	2.4	1.22	0.41	0.36	0.2	0.11	2.4	1 88	1.44	0.66
31	2.95	2.1	1.34	0.71	1.06	0.71	0.28	0.32	2.35	1.45	1.03	0.6
34	2.65	1.76	1.3	0.76	1.35	1.01	0.92	0.4	2.2	1.45	1.24	0.56
39	3.0	2.2	1.25	0.7	1.5	1.0	0.66	0.44	2.6	1.8	1.05	0.65
45	3.6	2.1	1.2	0.69	1.54	1.07	0.72	0.46	2.35	1.84	1.15	0.65
54	3.0	2.2	1.22	0.68	1.54	1.1	0.59	0.4	3.1	2.4	1.18	1.63
58	4.4	3.1	2.1	1.3	1.69	1.22	0.77	0.52	3.6	2.5	1.68	0.96
Average.	2.72	1.81	1.13	0.68	1.48	0.99	0.62	0.37	1.12	c.75	0.47	0.28

TABLE XV.—(INTENSITY SERIES.)

Showing the brightness measurements in candlepower per square inch for the different intensities used for the semi-indirect system at points indicated by the letters A, B, C, D, etc., see Fig. 3, Further Experiments on the Efficiency of the Eye, etc., TRANS. I. E. S. (1915), vol. X, p. 452b.

Position	800 watts	480 watts	320 watts	200 watts
A..................................	0.687	0.370	0.180	0.1428
B	0.0461	0.0219	0 01402	0.01008
C	0.0858	0.0504	0.0346	0.02414
D	0.0461	0.0219	0.0163	0.01008
E	0.00264	0.00177	0.0008	0.00061
F	0.0034	0.00187	0.001034	0.000792
G	0.0058	0.00242	0.00187	0.00123
H	0.00662	0.00259	0.00162	0.00144
I	0.00638	0.00237	0.00187	0.00123
J	0.00149	0.00076	0.c00484	0.000325
K	0.00462	0.00189	0.0014	0.000902
L..................................	0.00255	0.00173	0.001085	0.00063
M	0.00572	0.00224	0.001408	0.0011
N	0.00286	0.00173	0.001085	0.00063
O..................................	0.00704	0.00462	0.00264	0.00176
P	0.00616	0.003196	0.00198	0.00154
X	0.003432	0.00176	0.00105	0.000814
Reading page horizontal	0.0107	0.00462	0.0029	0.002024
Reading page 45° position	0.00654	0.00316	0.00193	0.00176

TABLE XVI.—(INTENSITY SERIES.)

Showing the brightness measurements in candlepower per square inch for the different intensities used for the direct system (16 lamps) at points indicated by the letters A, B, C, D, etc., see Fig. 2, Further Experiments on the Efficiency of the Eye, etc., TRANS. of the I. E. S., 1915, X, p. 452a.

Position	400 watts	365 watts	240 watts
A	1000.00000	1000.00000	1000.00000
B	0.1897	0.1232	0.1232
C	0.00253	0.00151	0.00151
D	0.00277	0.00145	0.00119
E	0.00097	0.00067	0.000545
F	0.00277	0.00185	0.00156
G	0.00303	0.00246	0.00172
H	0.00303	0.00229	0.00174
I	0.00316	0.00216	0.0018
J	0.00075	0.0004	0.000453
K	0.00252	0.00167	0.00176
L	0.00191	0.00149	0.00154
M	0.00273	0.00198	0.00194
N	0.00176	0.00145	0.00136
O	0.0026	0.00242	0.00143
P	0.00215	0.00167	0.00119
Q	0.00184	0.00103	0.00103
X	0.00172	0.00132	0.001
Reading page horizontal	0.00396	0.00405	0.00211
Reading page 45° position	0.0029	0.00273	0.00176

TABLE XVII.—(INTENSITY SERIES).

Showing the brightness measurements in candlepower per square inch for the different intensities used for the direct system (8 lamps) at points indicated by the letters A, B, C, D. etc., see Fig. 2, Further Tests for the Efficiency of the Eye, etc., TRANS. of the I. E. S., 1915, X, p. 452a.

Position	450 watts	320 watts	200 watts	120 watts
A	1000.00000	1000.00000	1000.00000	1000.00000
B	0.2953	0.2398	0.1657	0.08998
C	0.00317	0.00299	0.00154	0.00097
D	0.00454	0.0033	0.00185	0.000704
E	0.001848	0.00118	0.00059	0.0003
F	0.00198	0.00272	0.00145	0.00063
G	0.00347	0.00361	0.00189	0.00074
H	0.00391	0.00334	0.00122	0.0011
I	0.00405	0.0029	0.00167	0.00092
J	0.00069	0.00046	0.00037	0.00023
K	0.00308	0.00167	0.00122	0.00073
L	0.00229	0.00141	0.00103	0.00056
M	0.00387	0.00229	0.00141	0.00068
N	0.00192	0.00128	0.00096	0.00054
O	0.00246	0.00252	0.00101	0.00065
P	0.00192	0.00185	0.00083	0.00051
Q	0.00325	0.00222	0.00136	0.000704
X	0.002376	0.00141	0.000924	0.00062
Reading page horizontal	0.00528	0.00334	0.00229	0.00123
Reading page 45° position	0.003696	0.0022	0.00149	0.00077

TABLE XVIII.—(INTENSITY SERIES.)

Showing some prominent ratios of surface brightness for the different intensities used for the semi-indirect system.

Ratio	800	480	320	200
Lightest to darkest	0.687 /0.00149 = 455	0.37 /0.00076 = 486	0.18 /0.000484 = 372	0.1428 /0.000325 = 439
Lightest to test card	0.687 /0.00343 = 200	0.37 /0.00176 = 210	0.18 /0.00105 = 171	0·1428 /0.000814 = 175
Lightest to reading page ...	0.687 /0.00654 = 105	0.37 /0.00316 = 113	0.18 /0.00193 = 93	0.1428 /0.00176 = 81
2nd lightest to darkest	0.0858/0.00149 = 57	0.0504/0.00076 = 66	0.0346/0.000484 = 71	0.02414/0.000325 = 74
2nd lightest to test card	0.0858/0.00343 = 25	0.0504/0.00176 = 28	0.0346/0.00105 = 32	0.02414/0.000814 = 29
2nd lightest to reading page.	0.0858/0.00654 = 13	0.0504/0.00316 = 15	0.0346/0.00193 = 17	0.02414/0.00176 = 13
3rd lightest to darkest	0.0461/0.00149 = 31	0.0219/0.00076 = 29	0.0163/0.000484 = 34	0.01008/0.000325 = 31
3rd lightest to test card	0.0461/0.00343 = 13	0 0219/0.00176 = 12	0.0163/0.00105 = 15	0.01008/0.000814 = 12
3rd lightest to reading page.	0.0461/0.00654 = 7	0.0219/0.00316 = 6.9	0.0163/0.00193 = 8	0.01008/0.00176 = 6

TABLE XIX.—(INTENSITY SERIES).

Showing some prominent ratios of surface brightness for the different intensities used for the direct system (16 lamps).

Ratios	400	365	240
Lightest to darkest	1000.00000/0.00075 = 1,333,333	1000.00000/0.0004 = 2,500,000	1000.0000/0.000453 = 2,207,505
Lightest to test card	1000.00000/0.00172 = 581,395	1000.00000/0.00132 = 757,575	1000.0000/0.0011 = 909,090
Lightest to reading page	1000.00000/0.0029 = 344.828	1000.00000/0.00273 = 366,300	1000.0000/0.00176 = 568,181
2nd lightest to darkest	0.1897 /0.00075 = 253	0.1232 /0.0004 = 308	0.1232/0.000453 = 272
2nd lightest to test card	0.1897 /0.00172 = 110	0.1232 /0.00132 = 93	0.1232/0.0011 = 112
2nd lightest to reading page	0.1897 /0.0029 = 65	0.1232 /0.00273 = 46	0.1232/0.00176 = 70
3rd lightest to darkest	0.00316/0.00075 = 4.2	0.00246/0.0004 = 6.15	0.0018/0.000453 = 4
3rd lightest to test card	0.00316/0.00172 = 1.8	0.00246/0.00132 = 1.8	0.0018/0.0011 = 1.6
3rd lightest to reading page	0.00316/0.0029 = 1.1	0.00246/0.00273 = 0.9	0.0018/0.00176 = 1.02

TABLE XX.—(INTENSITY SERIES.)

Showing some prominent ratios of surface brightness for the different intensities used for the direct system (8 lamps).

Ratio	480	320	200	120
Lightest to darkest	1000.00000/0.00069 = 1,449,275	1000.0000/0.00046 = 2,173.913	1000.00000/0.00037 = 2,702.702	1000.000000/0.00023 = 4,347,826
Lightest to test card	1000.00000/0.002376 = 420,168	1000.0000/0.00141 = 709,220	1000.00000/0.000924 = 1,086,960	1000.000000/0.00062 = 1,612,903
Lightest to reading page	1000.00000/0.003696 = 270,270	1000.0000/0.0022 = 454,545	1000.00000/0.00149 = 671,141	1000.000000/0.00077 = 1,298,701
2nd lightest to darkest	0.2953 /0.00069 = 428	0.2298/0.00046 = 519	0.1657 /0.00037 = 449	0.08995 /0.00023 = 390
2nd lightest to test card	0.2953 /0.002376 = 124	0.2298/0.00141 = 170	0.1657 /0.000924 = 179	0.08995 /0.00062 = 128
2nd lightest to reading page	0.2953 /0.003696 = 80	0.2298/0.0022 = 109	0.1657 /0.00149 = 111	0.08995 /0.00077 = 117
3rd lightest to darkest	0.00454/0.00069 = 6.6	0.0033/0.00046 = 7.1	0.00185/0.00037 = 5.0	0.000704/0.00023 = 3.1
3rd lightest to test card	0.00454/0.002376 = 1.9	0.0033/0.00141 = 2.3	0.00185/0.000924 = 2.0	0.000704/0.00062 = 1.1
3rd lightest to reading page	0.00454/0.003696 = 1.2	0.0033/0.0022 = 1.5	0.00185/0.00149 = 1.2	0.000704/0.00077 = 0.9

TABLE XXI.—(INTENSITY SERIES.)

Observer R, showing the effect on the efficiency of the eye of varying the intensity of light in the semi-indirect lighting system.

Watts	Volts	Foot-candles			Time	Maximal distance at which test object can be seen clear	Working distance	Total time clear	Total time blurred	Total time clear ÷ total time blurred	Ratios reduced to common standard
		Horizontal	Vertical	45°							
320	107	2.2	0.58	1.52	9 A.M.	73.5	58.5	117	63	1.86	3.5
					12 M.	71.5	58.5	112	68	1.65	3.1
320	110	2.31	0.62	1.61	9 A.M.	74.0	57.0	140	40	3.5	3.5
					12 M.	72.0	57.0	135	45	3.0	3.0
200	110	1.72	0.484	1.29	9 A.M.	72.5	57.5	138	42	3.27	3.5
					12 M.	72.5	57.5	130	50	2.6	2.78
200	107	1.6	0.45	1.15	9 A.M.	65.5	51.5	141	39	3.61	3.5
					12 M.	65.5	51.5	123	57	2.14	2.07
480	107	3.3	0.94	2.4	9 A.M.	79.0	63.5	124	56	2.21	3.5
					12 M.	76.5	63.5	96	180	1.11	1.75
800	107	6.8	1.82	4.5	9 A.M.	85.5	66.5	126	54	2.33	3.5
					12 M.	82.5	66.5	62	118	0.525	0.78
760	107	5.8	1.45	4.0	9 A.M.	80.5	68.5	142	38	3.73	3.5
					12 M.	79.5	68.5	92	88	1.04	0.97

TABLE XXII.—(INTENSITY SERIES.)

Observer R, showing the effect on the efficiency of the eye of varying the intensity of light in the direct lighting system. (16 lamps.)

Watts	Volts	Foot-candles			Time	Maximal distance at which test object can be seen clear	Working distance	Total time clear	Total time blurred	Total time clear ÷ Total time blurred	Ratios reduced to common standard
		Horizontal	Vertical	45°							
240	107	1.23	0.54	0.935	9 A.M.	74.0	62.0	132	48	2.75	3.5
					12 M.	73.0	62.0	97	83	1.17	1.49
365	107	1.6	0.6	1.33	9 A.M.	74.5	64.0	111	69	1.61	3.5
					12 M.	74.0	64.0	68	112	0.607	1.32
400	107	1.86	0.8	1.46	9 A.M.	76.0	65.0	142	38	3.68	3.5
					12 M.	75.0	65.0	102	78	1.3	1.23
880	107	4.2	1.41	2.6	9 A.M.	81.0	68.0	139	41	3.39	3.5
					12 M.	78.0	68.0	71	109	0.65	0.67

TABLE XXIII.—(INTENSITY SERIES.)

Observer R, showing the effect on the efficiency of the eye of varying the intensity of light in the direct lighting system. (8 lamps.)

200	107	1.16	0.45	0.85	9 A.M.	72.0	56.0	122	58	2.1	3.5
					12 M.	71.0	56.0	105	75	1.4	2.3
120	107	0.64	0.32	0.49	9 A.M.	70.5	56.5	141	39	2.87	3.5
					12 M.	70.0	56.5	110	70	1.57	1.91
320	107	1.97	0.65	1.39	9 A.M.	73.5	60.5	137	43	3.18	3.5
					12 M.	73.0	60.5	107	73	1.46	1.6
480	107	2.6	1.02	2.0	9 A.M.	76.0	63.5	159	21	7.57	3.5
					12 M.	73.5	63.5	128	52	2.5	1.15

Showing the effect on the efficiency of the eye of varying the intensity of light in the semi-indirect lighting system.

	Watts	Volts	Foot-candles Hori-zontal	Foot-candles Verti-cal	45°
A	200	107	1.6	0.45	1.15
B	200	110	1.72	0.484	1.29
C	320	107	2.2	0.58	1.52
D	320	110	2.31	0.62	1.61
E	480	107	3.3	0.94	2.4
F	800	107	6.8	1.82	4.5
X	760	107	5.8	1.45	4.0

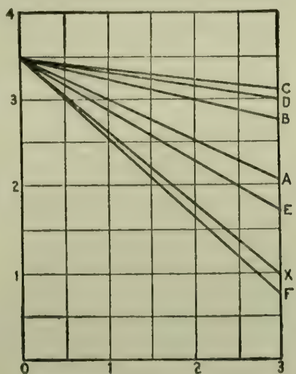


Chart C.

Showing the effect on the efficiency of the eye of varying ihe intensity of light in the direct lighting system. (16 lamps.)

	Watts	Volts	Foot-candles Hori-zontal	Foot-candles Verti-cal	45°
A	240	107	1.23	0.54	0.935
B	365	107	1.6	0.6	1.33
C	400	107	1.86	0.8	1.46
X	880	107	4.2	1.41	2.6

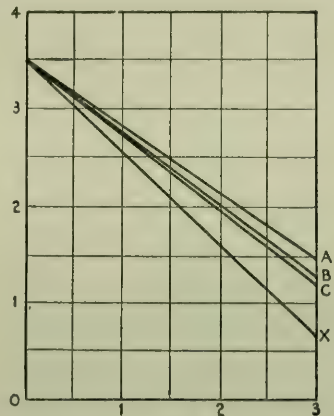


Chart D.

Showing the effect on the efficiency of the eye of varying the intensity of light in the direct lighting system. (8 lamps.)

	Watts	Volts	Foot-candles Hori-zontal	Foot-candles Verti-cal	45°
A	120	107	0.64	0.32	0.49
B	200	107	1.16	0.45	0 85
C	320	107	1.97	0.65	1.39
D	480	107	2.6	1.02	2.0

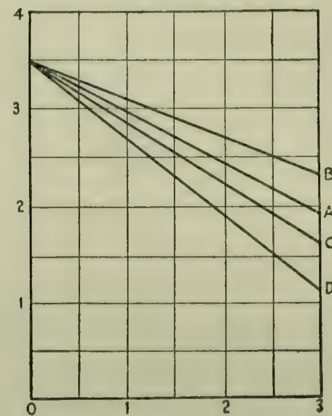


Chart E.

Chart F.—Showing the effect on the efficiency of the eye of varying the intensity of light for the semi-indirect system of lighting. Foot-candles at the point of the test card are plotted along the abscissa; loss of efficiency along the ordinate. X = points where the change in intensity was produced by changing the voltage (see Table XXI).

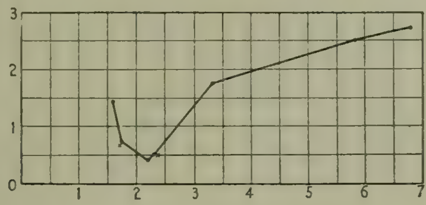


Chart F.

Chart G.—Showing the effect on the efficiency of the eye of varying the intensity of light for the direct system of lighting. Foot-candles at the point of the test card are plotted along the abscissa; and loss of efficiency along the ordinate. A = curve for 16 lamps; B, for 8 lamps.

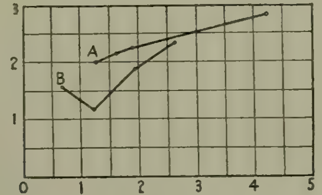


Chart G.

The results of the tests for the intensity series are shown in Tables XXI–XXIII. Three hours was selected as the period of work in all of these experiments. Briefly stated the procedure was as follows. First the most favorable intensity was determined and then variations were made on either side of this intensity until it was certain that the characteristic effect of increase and decrease of illumination was obtained. Table XXI gives the results for Observer R under the semi-indirect system. Seven variations of intensity were used. These results are typical of the effect of variations of intensities for this system. Tables XXII and XXIII show the results for the direct system for the same observer. For the direct system the most favorable intensity, it will be noted, was secured with the 8-lamp system with a total wattage lower than could be gotten with the 16-lamp system, *i. e.,* a system totalling 200 watts caused the least loss of efficiency to the eye, while 240 was the smallest total of wattage that could be secured with the 16-lamp system.

Charts have been constructed also to give a graphic representation of these tables. Chart C shows the results of Table XXI; Chart D, of Table XXII; and Chart E, of Table XXIII.

In these charts loss of efficiency was plotted against time of work. In Charts F and G loss of efficiency is plotted against intensity of light in foot-candles at the point of the test card. Chart F shows the results for Table XXI; Chart G for Tables XXII and XXIII.

IV. CONCLUSION.

Two facts may be emphasized at this point. (1) Of the lighting factors that influence the welfare of the eye, those we have grouped under the heading distribution are apparently fundamental. They seem to be the most important we have yet to deal with in our search for the conditions that give us the minimum loss of efficiency and the maximum comfort in seeing. If, for example, the light is well distributed in the field of vision and there are no extremes of surface brightness, our tests seem to indicate that the eye, so far as the problem of lighting is concerned, is practically independent of intensity. That is, when the proper distribution effects are obtained, intensities high enough to give maximum discrimination of detail may be employed

without causing appreciable damage or discomfort to the eye. (2) For the kind of distribution effects given by reflectors of the type employed in our direct and semi-indirect installations, our results show that unquestionably too much light is being used for the welfare of the eye.

Before concluding our paper we wish again to state that the units we have employed were not selected as fully representative of the classes direct, semi-indirect, and indirect. Agreement in fact has not yet been reached with regard to what falls within each of these classes. The units employed were chosen rather to show the effect on the ability of the eye to maintain its efficiency for a period of work of varying the factors we have grouped under the heading distribution. We hope ultimately to determine the limits between which each of these factors may vary without damage to the eye in a selected range of lighting situations, especially the factor surface brightness. These most favorable conditions will then serve as a goal to be attained whatever principle of lighting is employed.

Our next step in this division of the work will be to determine the effect on loss in efficiency of using reflectors of different degrees of opacity when the light is distributed to the plane of work both by the direct and indirect principles of lighting. That is, reflectors of different densities: prismatic, alba, opalux, totally opaque, etc., will be used turned up and down. In each case the installation wili be made with special reference to giving the best results obtainable for the particular type of unit employed; and the factors: evenness of illumination, diffuseness of light, the angle at which the light falls on the work, and the evenness of surface brightness will be varied separately in turn, and the effect on loss of efficiency will be determined. Moreover, if it is found that the factors in question can not be studied in sufficient detail in the concrete lighting situation, the work will be supplemented by more abstract investigations. The results of this series of tests should give us among other things, for example, a still better idea of what amount of brightness difference the eye is adapted to stand, and the comparative effect of different ratios of surface brightness on loss of efficiency.

FURTHER EXPERIMENTS ON THE EFFICIENCY OF THE EYE UNDER DIFFERENT CONDITIONS OF LIGHTING.*

BY C. E. FERREE AND G. RAND.

Synopsis: This paper is a continuation of the papers presented to the Society in 1912 and 1913. It describes the completion of the plan of work outlined in the preceding papers for one set of lighting conditions for three of the tests thus far devised by one of the writers (Ferree)—namely, a test of the ability of the eye to hold its efficiency for a period of work; a test for loss of efficiency of the fixation muscles; and a test for the comparative tendency of different conditions of lighting to produce discomfort. A report is also given of some miscellaneous experiments related to the hygienic employment of the eye in which the following points are taken up: the effect of varying the area and conversely the intrinsic brightness of the ceiling spots above the reflectors of an indirect system of lighting; the effect of varying the angle at which the light falls on the work in a given lighting situation; the effect of using an opaque eye shade with dark and light linings with each of the installations of artificial lighting employed in this and the previous work; the effect on the efficiency of the fixation muscles of three hours of work under these installations; the effect of motion pictures on the eye for different distances of the observer from the projection screen; a determination of the tendency of different conditions of lighting to produce discomfort, and a comparison of the tendency of these conditions to produce discomfort and to cause loss of efficiency.

INTRODUCTION.

The present paper is the third in a series of papers presented to this Society on the subject of lighting in its relation to the eye. In the first paper of this series[1] it was pointed out that if we are to make a comparative study of the effect of different conditions of lighting on the eye, we must have a means of estimating effects. Work was described in this paper in which

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

[1] Tests for the Efficiency of the Eye Under Different Systems of Illumination and a Preliminary Study of the Causes of Discomfort, TRANS. I. E. S., vol. VIII, 1913, pp. 40-60.

the tests already known to physiological optics had been applied to the problem with negative results. New tests were proposed and brief results were given to show their feasibility for the problem in hand and to some extent their sensitivity. The suggestion was made that a systematic investigation of the effect of different conditions of lighting on the eye should include a study of the following points: (1) the efficiency of the fresh eye, (2) the loss of efficiency as the result of a period of work, and (3) the tendency to produce discomfort. In the second paper of the series,[2] presented to the Society last year, a plan of work was outlined and in part carried out in which the first two of the above points were covered for a given set of lighting conditions. The following factors of importance to the eye were enumerated: the evenness of illumination, the diffuseness of light, the angle at which the light falls on the object viewed, the evenness of surface brightness, intensity and quality. The first four of these factors are very closely interrelated and are apt to vary together in a concrete lighting situation, although not in a 1 : 1 ratio. It was convenient, therefore, for the purpose of this first investigation, which was primarily explorative in character, to group them together under one heading and to refer to them as distribution factors. In order to investigate the effect of certain wide variations in these factors, tests were conducted under four types of lighting in common use: one was the lighting of a room by daylight from windows; the others were the lighting of the same room by units commonly called direct, semi-indirect, and indirect, selected to serve the purposes of the test.[3]

[2] "The Efficiency of the Eye Under Different Conditions of Lighting—The Effect of Varying the Distribution Factors and Intensity." TRANS. of the Ill. Eng. Soc., 1915, vol. X, pp. 407-447.

[3] According to the plan as the investigation proceeds, the effect of varying each of these factors separately will be studied. No especial attempt was made to do this in the previous study. In making the experimental variations necessary to the investigation, it was stated as our purpose to keep as close as possible to actual lighting situations. More abstract investigations will be resorted to only when it becomes necessary to supplement the results by details that cannot be gotten from the concrete investigation. The objection to the abstract type of investigation, as the writers see the case at the present time, is that its results are very apt to be misleading. That is, what is permissible with regard to one factor in isolation, may not be at all permissible in conjunction with other factors. A more feasible plan seems to us to be to vary the factor over a certain practical range in actual concrete situations. By a proper selection of the proper situations employed, the ground of all that is practicable in lighting may be covered, and the results obtained can have a safe application.

For the systems of artificial lighting the tests were made at four positions in the room; one at which six of the eight lighting units employed were in the field of view, one at which four were in the field of view, one at which two were in the field of view, and one at which none was in the field of view. This variation of position at which the observation was made accomplishes, it was pointed out, two purposes. (1) It gives a more representative idea of the difference in the effect on the eye of the four types of lighting employed. And (2) it shows the effect of varying the number of surfaces in the field of view presenting brightness differences, more particularly the number of primary sources. The effect of varying intensity under each of the above conditions of distribution was also tested. The two sets of experiments were called respectively the distribution and intensity series. Results were given in the preceding paper for only one of the above positions in the distribution series, and for only the direct and semi-indirect systems for the intensity series. The results of the remainder of these two series of experiments, together with the report of some miscellaneous experiments will constitute the subject matter of the present paper. In these miscellaneous experiments, the following points have been taken up: the effect of varying the area and conversely the intrinsic brightness of the ceiling spots above the reflectors for the indirect system; the effect of varying the angle at which the light falls on the work; the effect of using an eye shade with dark and light linings with each of the three installations of artificial lighting; the effect on the efficiency of the fixation muscles of the eye of three hours of work under each of the conditions of lighting described in the distribution and intensity series; the effect of motion pictures on the eye for different distances of the observer from the projection screen; a determination of the tendency of each of the conditions of lighting that have been used in these experiments to produce discomfort, and a comparison of the tendency to produce discomfort and to cause loss of efficiency. Besides including some additional matter, these experiments, in connection with those of the preceding paper, complete the plan of work we had outlined for one set of lighting conditions for three of the tests we have thus far devised, namely, a test

for the ability of the eye to hold its efficiency for clear seeing for a period of work, a test for loss of efficiency of the fixation muscles, and a test for the comparative tendency of the different conditions of lighting to produce discomfort, with the exception that in a further analysis of the loss of efficiency caused by these lighting conditions, which will be carried out in part by means of these tests, data will be added later to show still more clearly the relative amounts of loss that are sustained by the different functions of the visual apparatus.

DISTRIBUTION SERIES.

As was pointed out in the former paper, in order to get the effect of variation in the distribution factors on the eye's loss of efficiency as the result of a period of work, the test should be conducted with the quality and intensity of light made as nearly equal as possible. The quality of light was made approximately the same for the three installations of artificial lighting employed by using clear tungsten lamps in each case. It was decided to make the intensity of light as nearly equal[4] as possible at the point of test, and to give a supplementary specification of the lighting effects in the remainder of the room for the three installations of artificial light.

At the point of test the light was photometered[5] in several directions. It was made approximately equal in the plane of the test card and as nearly as possible equal in the other directions. The specification of the lighting effects in the remainder of the room was accomplished as follows: (1) A determination was made of the average illumination of the room under each of the three installations. The room was laid out in 3-ft. (0.9 m.)

[4] This equalization was made at the point of test for the position of the observer with six of the fixtures in the field of view. For the other positions illumination measurements were made in several directions at the test card, and brightness measurements were made of the surface of the test card and of the observer's book held in the horizontal and 45 deg. positions. Equalization could not have been made at all of these points without having changed the relation and magnitude of the distribution factors, which would not have been in accord with the purpose of the test, namely, to determine the effect of a certain grouping or relation of these factors for the four positions in the room.

[5] We have not as yet made the fuller photometric specifications of the room lighted by daylight with our present arrangement of windows, curtains, etc. We hope to make the effect of distribution factors in daylight illumination (employing windows, skylights, etc.) the subject of a future study. In this study a photometric analysis of the illumination effects produced will be made an especial feature.

squares and illumination measurements were made at 66 of the intersections of the sides of these squares. Readings were taken in a plane 122 cm. above the floor with the receiving test plate of the illuminometer in the horizontal, the 45 deg. and 90 deg. positions measuring respectively the vertical, the 45 deg., and horizontal components of illumination. The 122 cm. plane was chosen because that was the height of the test object. (2) A determination was made of the brightness of prominent objects in the room, such as the test card, the reflectors for the semi-indirect installation, the reading page, the specular reflection from surfaces, etc. The brightness measurements were made by means of a Sharp-Millar illuminometer with the receiving test plate removed. The instrument was calibrated against a magnesium oxide surface obtained by depositing the oxide from the burning metal on a white card. By this method the reflecting surfaces were used as detached test plates. The readings were converted into candle-power per sq. in. by the following formula:

$$\text{Brightness} = \text{Foot-candles}/\pi \times 144.$$

(3) Photographs were made of the room from three positions under each system of illumination.

A complete specification of the test room, the types of installation used, and the illumination effects produced for the systems of lighting, is given in the previous paper which appears elsewhere in this number of the TRANSACTIONS (pp. 413-422). Only such data will be repeated here as are necessary for reference.[7]

In Fig. 1 the test room is shown drawn to scale: plan of room, north, south, east and west elevations. In the drawing, plan of room, are shown the 66 stations at which the illumination measurements were made, and the positions of the outlets for the lighting fixtures, A, B, C, D, E, F, G, and H. In the drawing, east elevation, the observer in position at one of the points (Position I) at which the tests were taken is repre-

[7] For a description of the *test* see the previous article referred to above (pp. 410-413); also Tests for the Efficiency of the Eye Under Different Systems of Illumination and a Preliminary Study of the Causes of Discomfort, TRANS. I. E. S., vol. VIII (1913), pp. 41-51.

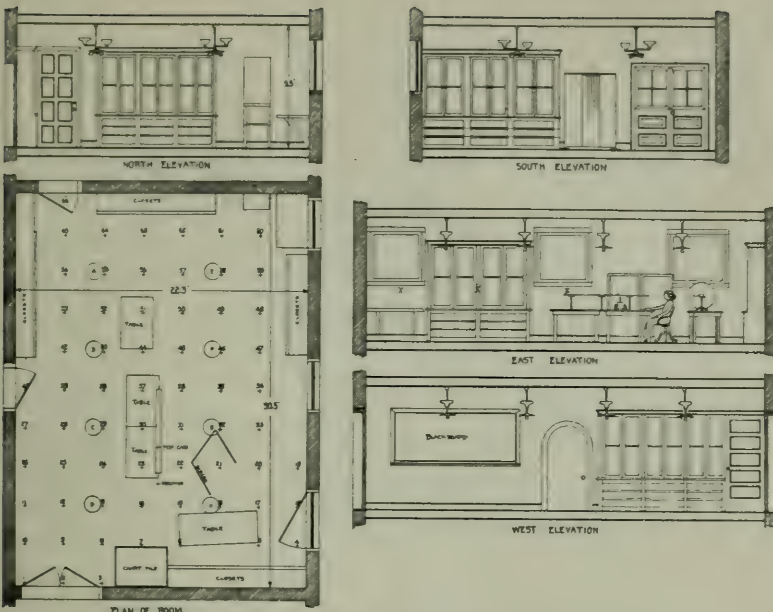


Fig. 1.—Plan of test room.

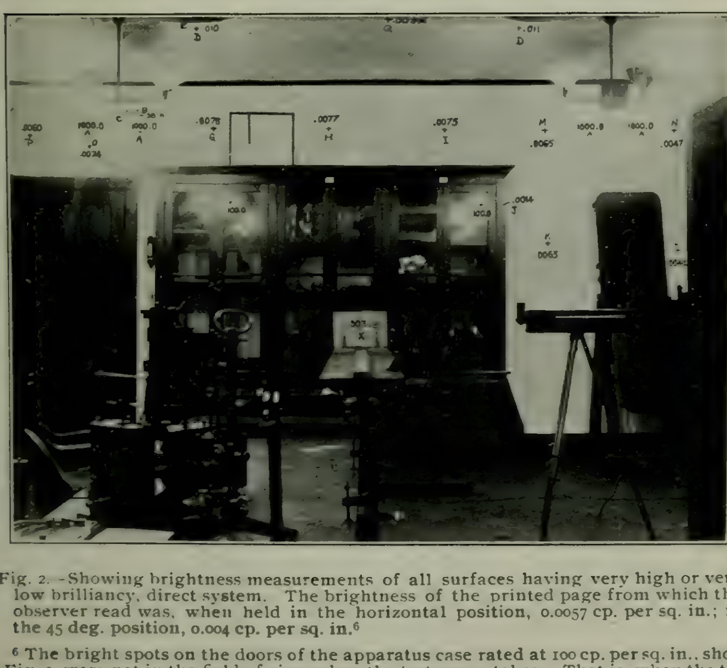


Fig. 2.—Showing brightness measurements of all surfaces having very high or very low brilliancy, direct system. The brightness of the printed page from which the observer read was, when held in the horizontal position, 0.0057 cp. per sq. in.; in the 45 deg. position, 0.004 cp. per sq. in.[6]

[6] The bright spots on the doors of the apparatus case rated at 100 cp. per sq. in., shown in Fig. 2, were not in the field of view when the tests were taken. That is, when the tests were taken, the doors were thrown open, and all of the apparatus which might give specular reflection was removed.

Fig. 3.—Showing brightness measurements of all surfaces having very high or very low brilliancy, semi-indirect system. The brightness of the printed page from which the observer read was, when held in the horizontal position, 0.0058 cp. per sq. in.; in the 45 deg. position, 0.0039 cp. per sq. in.

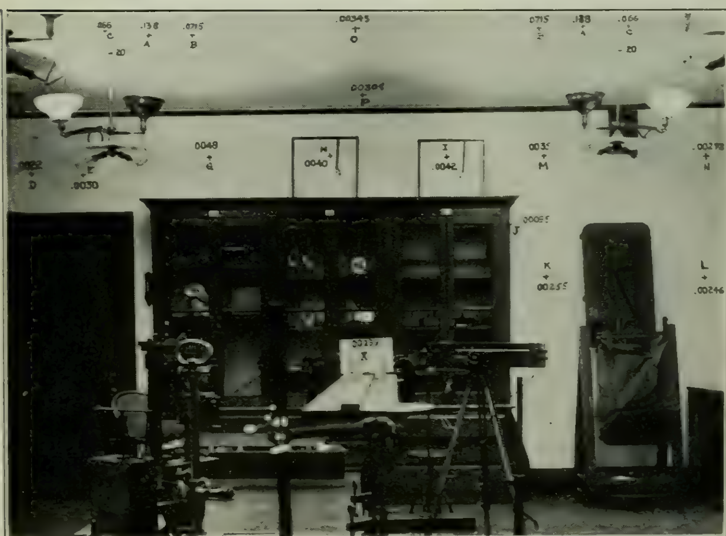


Fig. 4.—Showing brightness measurements of all surfaces having very high or very low brilliancy, indirect system. The brightness of the printed page from which the observer read was, when held in the horizontal position, 0.0058 cp. per sq. in.: in the 45 deg. position, 0.0043 cp. per sq. in.

sented.[8] The other three positions are indicated in the photographs by (x). They will be referred to in the tables and charts, in order, by the numerals II, III, and IV.

Table I shows the number and wattage of the lamps used at the outlets A, B, C, D, E, F, G, and H; and Table II shows the illumination measurements for each of the 66 stations represented in Fig. I. These measurements were made with the receiving test plate of the photometer in the horizontal, vertical and 45 deg. planes.[9]

[8] The track along which the test card was moved was parallel to the east and west walls of the room. During the three hours of reading which intervened between the two tests, the observer moved just far enough back from the upright supporting the mouth-board to give room for the book to be held and to permit of a comfortable reading position. The book was elevated and held approximately at an angle of 45 deg. When taking the test, the observer faced the north wall of the room, in such a position that with the eyes in the primary position, the lines of regard were parallel with the east and west walls of the room. Care was taken to have print of uniform size and distinctness for use with the three systems and to have a page which gave a comparatively small amount of specular reflection.

[9] See also Table III, The Efficiency of the Eye Under Different Conditions of Lighting, etc., TRANS. I. E. S., vol. X, 1915, p. 416a. This table was compiled as a supplement to Table II for the purpose of making a comparative showing of the evenness of illumination at the 122 cm. level given by the three systems of lighting. Two cases were made of this. (1) Comparisons were made of each component from station to station; (2) the difference between the components was compared. To facilitate these comparisons (a) the mean variation from the average of each of the components was computed; and (b) the difference between the averages of the three components was determined. The evenness of the illumination, it will be remembered, is not only of importance to the efficiency of the eye with reference to the object directly viewed; but also in its influence on the distribution of surface brightness. The evenness of surface brightness depends in general upon two sets of factors; (1) the nature and position of the reflecting surfaces in the room; and (2) the type of delivery of light to these surfaces.

We realize that the evenness of the illumination on the 122 cm. plane given by the indirect and semi-indirect units was somewhat interfered with by the reflectors of the direct system which were beneath and a little to the right of these units when in position for the test. Also the evenness of surface brightness on the ceiling for the direct system was interfered with by the indirect and semi-indirect reflectors which were above and a little to the side of the direct units. The influence of this "dead apparatus" will be eliminated in the next series of installations. Moreover, the installation in each case was not such as to give the best effects obtainable from the type of reflector used. For example, the indirect reflectors were too close to the ceiling to give the maximum evenness of illumination and surface brightness for the type of reflector employed. The analysis of the effects given in the former paper was not made, therefore, for the purpose of drawing general conclusions with regard to the type of reflector used. It was made solely for the sake of the comparison of the illumination effects obtained with the corresponding results for loss of efficiency.

TABLE I.

Showing the number and wattage of the lamps used at outlets A, B, C, D, E, F, G and H.

Outlet	Direct Watts	Semi-indirect Watts	Indirect Watts
A	2–60	1–100	1–100
B	2–60	1–100	1–100
C	2–60	1–100	1–100
D	2–40	1–100	1–100
E	2–60	1–100	1–100
F	2–60	1–100	1–100
G	2–60	1–100	1–100
H	2–40	1– 60	1–100

TABLE II.—DISTRIBUTION SERIES.[10]

Showing the illumination measurements in foot-candles for each of the 66 stations represented in Fig. 1 for the direct, semi-indirect, and indirect systems used.

	Horizontal			Vertical			45°		
Station	Direct	Semi-indirect	Indirect	Direct	Semi-indirect	Indirect	Direct	Semi-indirect	Indirect
1	1.41	1.44	1.22						
2	1.32	1.47	1.26						
3	1.10	1.40	1.32						
4	1.37	1.10	1.47						
5	2.03	2.58	2.20						
6	2.50	3.20	2.95						
7	2.51	3.60	2.90						
8	3.30	3.75	3.00						
9	2.78	2.53	2.20						
10	1.50	1.59	1.35						
11	2.12	1.64	1.66						
12	4.20	2.65	2.70	0.47	0.48	0.47	2.40	1.25	1.43
13	6.10	5.25	4.10	0.47	0.48	0.42	3.30	2.25	1.96
14	3.70	4.95	4.40	0.48	0.47	0.47	2.00	2.40	2.30
15	3.00	4.85	4.50	0.44	0.48	0.47	1.97	1.88	2.30
16	6.60	4.25	4.10	0.70	0.37	0.48	3.58	1.60	2.10
17	4.65	2.35	3.15	0.48	0.24	0.46	1.80	0.69	1.60
18	2.15	1.69	2.20	0.49	0.38	0.47	1.10	0.66	1.63
19	2.95	2.10	2.50						
20	5.30	3.20	3.40	1.62	0.53	0.86	3.00	2.30	2.20
21	6.60	4.80	4.60	2.00	0.71	0.94	3.60	1.85	3.00
22	2.25	4.40	4.80	0.61	0.69	1.07	1.15	1.80	2.90
23	4.50	6.00	5.10	1.20	1.14	1.10	2.18	3.30	2.90
24	6.95	5.40	5.00	1.76	1.30	1.04	3.60	3.10	3.00
25	4.85	3.72	3.50	1.33	0.78	0.75	2.75	1.85	2.10
26	2.50	1.82	2.20						
27	2.81	2.05	2.40						
28	6.50	3.28	3.70	1.30	1.11	1.12	4.40	2.10	2.50
29	9.00	6.40	5.20	1.45	1.50	1.48	6.30	3.60	3.40
30	4.95	6.95	5.40	1.36	1.46	1.40	3.15	4.15	3.60
31	4.80	6.20	5.20	0.77	1.20	1.24	2.78	3.85	3.60

TABLE II.—DISTRIBUTION SERIES.—(*Continued.*)

	Horizontal			Vertical			45°		
Station	Direct	Semi-indirect	Indirect	Direct	Semi-indirect	Indirect	Direct	Semi-indirect	Indirect
32	9.20	5.50	5.00	0.47	0.28	1.33	5.20	2.25	3.40
33	6.20	3.18	3.70	1.54	0.75	1.22	4.60	1.83	2.60
34	5.75	4.30	4.00	2.85	1.20	1.46	4.30	2.92	3.10
35	8.00	6.90	5.40	3.70	1.70	1.65	6.00	4.40	4.90
36	5.60	7.25	5.30	2.35	1.91	1.65	4.20	4.68	4.00
37	5.45	7.00	5.80	2.18	2.15	1.82	3.78	4.55	4.00
38	8.25	6.80	5.40	3.60	2.20	1.72	6.00	4.60	3.80
39	6.35	3.70	4.00	2.80	1.40	1.43	4.60	2.80	3.00
40	3.00	2.05	2.30						
41	2.70	1.73	2.10						
42	7.30	3.65	3.50	2.50	1.64	1.36	5.40	2.93	2.80
43	9.80	6.90	5.00	2.70	2.08	1.78	7.20	4.50	3.90
44	5.50	7.10	5.20	2.42	2.18	1.88	4.35	5.10	4.30
45	5.45	8.00	5.20	2.60	2.00	1.93	4.80	5.30	4.20
46	10.00	7.70	5.20	2.75	1.90	1.86	8.00	5.40	4.10
47	6.60	4.20	3.60	2.45	1.56	1.33	5.30	3.05	2.90
48	5.80	4.35	3.70	3.20	1.69	1.74	5.00	3.60	3.30
49	8.40	7.20	4.80	4.30	2.55	2.10	7.20	5.80	4.00
50	5.50	7.70	4.90	3.35	2.42	2.10	8.50	5.80	4.10
51	5.40	6.80	5.00	3.05	2.68	2.15	4.60	5.35	4.35
52	8.00	6.40	4.70	4.20	2.55	1.93	6.50	4.82	4.00
53	6.60	3.85	3.60	3.00	1.77	1.41	5.00	3.20	3.00
54	6.95	2.88	2.80	2.62	1.80	1.50	5.80	3.00	2.90
55	9.00	5.90	3.90	3.15	2.40	1.94	8.00	5.20	3.75
56	4.95	5.90	4.60	3.15	2.50	2.10	5.30	5.80	4.40
57	4.65	6.10	4.50	3.00	2.60	2.20	4.65	5.80	4.40
58	9.75	6.35	4.00	3.35	2.58	2.00	8.50	5.80	4.00
59	5.85	3.20	2.90	2.98	1.90	1.76	5.60	3.62	3.10
60	3.85	2.57	2.60			1.66			2.90
61	5.20	4.20	3.10	4.45	2.60	1.90	7.80	5.40	3.50
62	3.30	4.20	3.20	3.30	2.95	2.10	4.95	5.70	3.70
63	3.52	4.20	3.00	3.60	2.80	2.20	5.60	5.00	3.50
64	5.40	3.70	3.10	4.60	2.45	1.93	7.65	4.60	3.40
65	4.15	2.40	2.25	4.00	1.79	1.54	5.50	2.82	2.60
66	2.10	1.42	1.35						
Average	5.0	4.27	3.61	2.32	1.59	1.48	4.77	3.63	3.30

[10] Reduced to equal wattages (800 watts) these installations give the following average illumination values in foot-candles for the receiving test plate in the positions specified above: Direct system: horizontal, 4.54; vertical, 2.2; 45°, 4.33. Semi-indirect system: horizontal, 4.49; vertical, 1.67; 45°, 3.82. Indirect: horizontal, 3.61; vertical, 1.48; 45°, 3.3.

It may not be out of place to suggest here that a careful study of the illuminating efficiency of different types of lighting units should be made under conditions that are strictly comparable for a wide range of variation. Such tests should be made under common supervision in a model room so constructed as readily to permit of the kind of variations needed; and should be, if possible, paralleled by tests for the efficiency of the eye. In working towards a reconstruction of lighting conditions, it is obvious that tests for the efficiency of the eye and for illuminating efficiency should go hand in hand.

Figs. 2, 3 and 4 are taken from the series of 9 photographs (see Figs. 2-10, op. cit., pp. 416b-416d) showing the illumination effects produced by the three systems of lighting. In these figures are given the brightness measurements of all surfaces having very high or very low brilliancy. The spot measured is indicated by a cross and the numerical value of the brightness measurement in candlepower per square inch is printed nearby. These spots are also lettered for convenience of reference in the intensity series. That is, since several installations were used in the intensity series, it was found convenient to express these values in tabular form and to identify them with the surfaces measured by means of letters. These photographs were taken from a point in line with the four positions of the observer as near to the south wall of the room as was possible; but owing to the narrow field of the camera as compared with the binocular field, these views include, for example, only about one-half of the field of vision of the observer at the test station nearest to this wall of the room. The camera's field in this position corresponds in fact very closely to the field presented to the observer seated at the center of the room. While, therefore, not all of his field of view for all of the positions at which tests were made is covered by the brightness measurements shown in the photographs, still the order of brightness difference present in the field of view for the different systems is well represented by these measurements, as can be seen by an inspection of the preceding photographs (see also Figs. 2-10, op. cit., pp. 416b-416d) and from the descriptions of the installations used. In order to facilitate certain features of comparison such as, for example, the evenness of surface brightness for each system for all of the room; for all of the room but the sources of light; and for all of the room but the sources and the spots above the sources, the brightness measurements shown in Figs. 2, 3 and 4 are also given in tabular form. These measurements and the letters identifying them with the surfaces measured, are given in Table III. In making the comparison it should be noted that the spots mentioned are not in all cases identical for the three systems. That is, owing to the different effects produced by the different reflectors, the same spots were not always conspicuously light or dark for the three systems. The letters, E,

F, G, etc., may then refer to entirely different spots in case of the three systems.

TABLE III.—DISTRIBUTION SERIES.

Showing the brightness measurements in candlepower per square inch for the surfaces A, B, C, D., etc., see Figs. 2, 3 and 4.

Surface measured	Direct system	Semi-indirect system	Indirect system
A	1000.0000	0.710	0.138
B	0.3816	0.057	0.0715
C	0.517	0.093	0.066
D	0.010	0.059	0.0022
E	0.00296	0.0029	0.0030
F	0.0044	0.0033	0.00123
G	0.0078	0.0053	0.0049
H	0.0077	0.006	0.0040
I	0.0075	0.0062	0.0042
J	0.0014	0.0010	0.00095
K	0.0063	0.0046	0.00255
L	0.0042	0.0027	0.00246
M	0.0065	0.0051	0.00352
N	0.0047	0.0027	0.00272
O	0.0074	0.0066	0.00343
P	0.006	0.00484	0.00308
Q	0.00396		

TABLE IV.—DISTRIBUTION SERIES.

Showing the brightness measurements in candlepower per sq. in. of the test card, reading page horizontal, and reading page in the 45 deg. position for Positions I, II, III, and IV, for the direct, semi-indirect, and indirect systems.

Position of observer	Surface measured	Direct system	Semi-indirect system	Indirect system
I	Test card	0.00308	0.0030	0.00299
	Reading page horizontal	0.0057	0.0058	0.0088
	Reading page 45° position	0.004	0.0039	0.00431
II	Test card	0.00506	0.00453	0.0046
	Reading page horizontal	0.0088	0.0107	0.0088
	Reading page 45° position	0.0068	0.00726	0.00792
III	Test card	0.0055	0.00462	0.00453
	Reading page horizontal	0.0092	0.0087	0.00814
	Reading page 45° position	0.00704	0.0077	0.00594
IV	Test card	0.0066	0.00475	0.00453
	Reading page horizontal	0.00814	0.00572	0.00572
	Reading page 45° position	0.0063	0.00484	0.00484

In Table IV are given the brightness measurements in candlepower per square inch for the test card and the reading page for the four positions of the observer: I, II, III and IV, for the direct, semi-indirect and indirect systems. The measurements of the reading page were taken at the point of work for the four positions of the observer with the book in the horizontal and 45 deg. position. During work the book was held in the 45 deg. position.

In Tables V and VI are shown some prominent ratios of sur-

face brightness for the three systems.[11] (See also Table VIII, op. cit., p. 421.)[12]

In compiling these ratios it has been considered important to make a comparative showing for the three systems (a) of the extremes of surface brightness; and (b) of the relation of the brilliancy of objects in the surrounding field to the surface brightness at the point of work. The extremes of surface brightness

[11] In attempting to make comparisons of the effect of the different magnitudes of brightness ratios, one obviously must bear in mind that the surfaces between which the ratios are established are not in all cases in the same position in the field of vision for the three systems. For example, the brightest surfaces in case of the indirect system, namely, the spots on the ceiling directly above the reflectors, are farther removed from the direct line of vision of the observer in the working position than were the brightest surfaces in case of the direct and semi-indirect systems. The position of the surface in the field of vision would come into question, for example, in making a determination of the maximum value of brightness difference the eye is adapted to stand. While we have done a great deal of work on the effect of position of the brilliant surface in the field of vision in our investigation of the causes of discomfort, we have made no especial investigation of this point in relation to loss of efficiency. Doubtless what we shall all have to bear in mind is that, even in the end, we cannot hope to specify narrowly what is most favorable, etc. In lighting conditions. The factors that enter into the concrete lighting situation are so complex or rather are so variable and so rarely duplicated that we can hope to make general specifications with regard to what is most favorable, for example, only within very broad limits. If one wishes to work the conditions down to a finer point than this, the particular installation must be tested *in situ*. We are at present working on a test which we hope will serve this purpose better than the test which has been used in the work described in the preceding papers.

[12] Table VIII, (op. cit., p. 421) was compiled from Tables IV-VII of that paper to show the mean variation in surface brightness for all the surfaces measured for the direct, semi-indirect, and indirect systems. In referring back to that paper it may not be out of place to call to mind again that the percentages given in Table VIII seem to indicate that the great advantage of the indirect over the other systems of lighting we have used with regard to the factor, evenness of surface brightness, comes, primarily at least, from its provisions for shielding the eye from the light source rather than from any conspicuously greater evenness of illumination given by it to the objects in the field of view. In fact, as may be seen from that table, all the systems give a fairly even distribution of surface brightness outside of the source and the surfaces immediately surrounding it.

The need of keeping surface brightness within certain limits and the primary importance of properly shielding the eye from the source, to the accomplishment of this desideratum, are obvious. Doubtless many ways will be devised in course of time for cutting down useless and harmful brightness differences in lighting effects. For example, the possibility is here suggested of producing a still smaller brightness difference than is given by the indirect reflectors of the type we have employed, by using semi-indirect reflectors of such a density as to give a surface brilliancy equal to that of the spot of light cast upon the ceiling. The value of this brilliancy, because of the larger area of luminous surface presented, could then be made smaller than that of the ceiling spot cast by the indirect reflector and still give the same amount of light to the room. A similar effect may be obtained with the indirect reflector by using lamps of lesser wattage and adding the light needed to make up the deficiency by installing directly beneath the reflector lamps of low wattage in translucent enclosures of a density that gives a surface brilliancy equal to that of the ceiling spots. The effect of both of these devices would be to lower the surface brilliancy for a given light flux by increasing the area of the luminous surface. Whether either device would be advisable from other standpoints we are not at present prepared to say.

are shown by giving the ratios between surfaces of the first, second, third, etc., order of brilliancy and the surface of the lowest order of brilliancy; and the comparison of the brilliancy of objects in the surrounding field to the brightness at the point of work by giving the ratios of the surfaces of the first, second, and third order of brilliancy to the brightness of the test card and the reading page in the working position. The following points may be noted. (1) The illumination effects produced by the direct system are characterized by great extremes of surface brightness, and a high ratio of brilliancy of objects in the surrounding field to the surface brightness at the point of work. These effects are much less pronounced for the semi-indirect system and still less for the indirect. (2) A comparison of this table with the tables giving loss of efficiency as the result of work shows that while the extremes of surface brightness are enormously larger for the direct than for the semi-indirect system, the eye loses almost as much in efficiency for three hours of work under the semi-indirect as under the direct system. That is, the greatest ratio of brightness for the direct system is over one thousand times as much as the greatest ratio for the semi-indirect, while the difference in loss of efficiency for the two systems is comparatively insignificant. On the other hand, the greatest ratio of brightness for the semi-indirect system is only about five times as much as for the indirect; while the difference in loss of efficiency for three hours of work is very large, this loss of efficiency for three hours of work for the indirect system being, it will be noted, very small indeed. This seems to indicate (a) that for the scale of brightness magnitudes and the illumination effects present in this series of experiments the gradation of surface brightness for the indirect system is very close to what the eye is adapted to stand without loss of efficiency; and (b) that an increase in difference in brightness above this point is followed at first by a rapid increase in loss of efficiency and later by a much slower increase. In the intensity series, in the work of the former paper, it will be remembered, the following points also came out. (1) The effect of size of ratio on loss of efficiency is different for different orders of magnitude of brightness. And (2) the size of the brilliant object, as

well as its brilliancy, is of importance. That is, within certain limits, as yet undefined, an increase in the area of the brilliant surface causes an increase in loss of efficiency.

In Table V the ratios were compiled from measurements showing the extremes of brightness of prominent surfaces in the room. In Table VI they were compiled to show the relation of the brilliancy of objects in the surrounding field to the surface brightness at the point of work for the positions of the observer, I, II, III and IV[13] (see Fig. 1, p. 452a). In general a falling off in the magnitude of brightness differences in the field of view will be noted in order from the Positions I to IV. This falling off is greatest for the direct system, next greatest for the semi-indirect, and least for the indirect. Thus there is not only a decrease in the number of surfaces in the field of view showing a high brilliancy from Positions I to IV, but also a decrease in the magnitude of brightness difference between the surfaces of high brilliancy and the test card, between these surfaces and the reading page, etc., especially for the direct and semi-indirect systems. An inspection of the table for loss of efficiency shows, roughly speaking, a correspondingly marked decrease in loss of efficiency from Positions I to IV for the systems which show the marked decrease in brightness difference, that is, for the direct and semi-indirect systems. The decrease in loss of efficiency, it will be noted, is practically nothing for the indirect system. Thus not only much less loss of efficiency is sustained by the eye for the indirect units used, but the results are much more independent of the position of the observer in the room.

The loss of efficiency for the Positions I, II, III and IV for the three systems is shown in Table VII.[14]

[13] It may also be of interest to the reader to work out for these four positions the ratios: lightest to darkest, darkest to test card, darkest to reading page, etc.

[14] Obviously in the consideration of the effect of a given lighting situation on the ability of the eye to hold its efficiency for a period of work, the age of the observer and the condition of his eyes should be taken into account. All the observers that have been employed by us in this work were under 26 years of age. Following is a clinic report of the eyes of the observer whose results are given in the following table, made by Dr. Wm. Campbell Posey of Philadelphia.

Observer R.

With glasses.—Vision of right eye = 20/25. Far muscle test = 0 ½ esophoria.
Vision of left eye = 20/20. Near muscle test = orthophoria.

Ophthalmoscopic examination.—Right eye = mixed astigmatism, ½ diopter.
Left eye = hyperopic astigmatism, 1½ diopters.

(*Continued on next page.*)

Chart I gives a graphic representation of the results of this table. Loss of efficiency is plotted along the ordinate and time of work along the abscissa. Each of the large squares along the abscissa represents an hour of work and along the ordinate an integer of the ratio, time clear to time blurred. The effect on loss of efficiency of the number and magnitude of brightness of surfaces of high brilliancy, especially of primary sources, in the field of view is obvious from these charts. The chart for position IV, however, shows that there is still a considerable difference in the loss of efficiency produced by the three systems, even when there are no sources or other surfaces of high brilliancy in the field of view. The indirect system still gives the least loss of efficiency, the semi-indirect next, and the direct the most. As may be seen in Figs. 2, 3, and 4, and in Tables III and VI there was little difference in the evenness of surface brightness in the field of view presented to the observer in this position, certainly none that could be considered of consequence in favor of the indirect system. The above results seem to indicate, therefore, that while the evenness of surface brightness is an important factor it is not the only factor in a lighting situation which may influence the amount of loss of efficiency sustained by the eye as the result of a period of work.

We wish to repeat in this paper what was very strongly emphasized in our former paper, namely, that the units we have employed were not selected as fully representative of the classes direct, semi-indirect, and indirect. Agreement in fact has not yet been reached with regard to what falls within each of these

External condition.—Adduction good; eyes slightly divergent under cover: cornea clear; pupils, 2½ mm.; irides respond equally and freely to light, accommodation, and convergence stimuli.

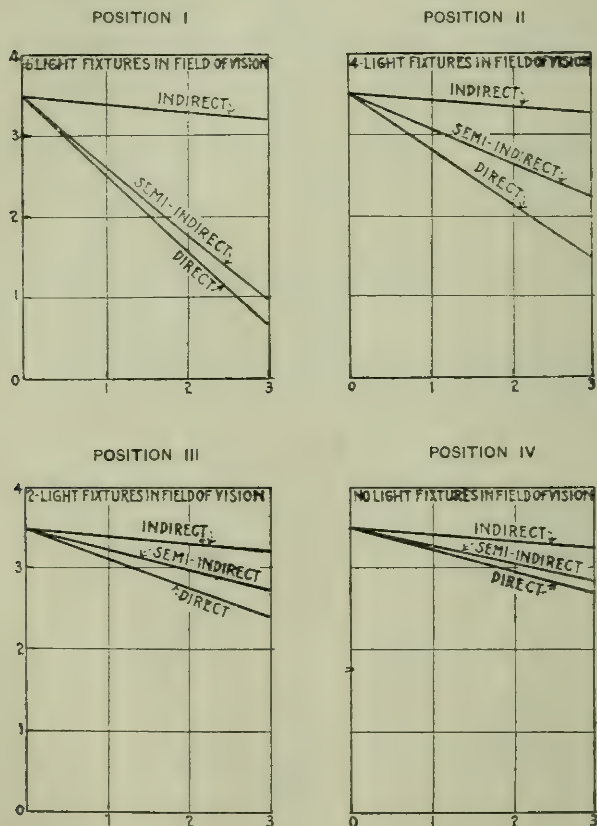
Glasses worn during test.—Right eye = —S., 0.50 D.;—C., 0.37D., x 160°
Left eye = —C., 0.50 D., x 180°

Lest the former paper has not appeared in print before this one is presented it may be well to make some mention here also of the reproducibility of results that may be obtained for our test for loss of efficiency. The mean variation of the ratio, time clear to time blurred for the same observer working under conditions as nearly constant as possible, is very small indeed. The order of magnitude of the mean variation of the test for the fresh eye was obtained as follows. Beginning at 9 A. M. five 3 minute tests were run with a rest period of 20 minutes between each test This was done with all observers on several days under each system of lighting employed. The rest period was taken in each case in a room lighted by daylight, with the observer facing a wall with an evenly lighted matt surface. For a single series of five tests the variation in the time seen clear in the 3 minute periods have always fallen within 1 per cent. for all of the observers we have used and for all systems of lighting.

classes. The units employed were chosen rather to show the effect of varying the factors we have grouped under the heading of distribution on the ability of the eye to maintain its efficiency for a period of work. We hope ultimately to determine the

CHART I.—DISTRIBUTION SERIES.

Showing the effect on loss of efficiency of varying the observer's position in the room, or the number of bright sources, primary and secondary, in the field of vision.



limits between which each of these factors may vary in a selected range of lighting situations, without damage to the eye, especially the factor surface brightness. These most favorable conditions will then serve as a goal to be attained whatever principal of lighting is employed.

TABLE V.—DISTRIBUTION SERIES.

Ratios showing the extremes of surface brightness for the direct, semi-direct, and indirect systems used.

Ratio	Direct system	Semi-indirect system	Indirect system
Lightest to darkest	1000/0.0014 = 714,285	0.710 /0.001 = 710	0.138 /0.00095 = 145
2nd lightest to darkest	0.3816/0.0014 = 123.9	0.093 /0.001 = 93.0	0.0715 /0.00095 = 75.2
3rd lightest to darkest	0.0517/0.0014 = 37.0	0.059 /0.001 = 59.0	0.066 /0.00095 = 69.4
4th lightest to darkest	0.01 /0.0014 = 7.14	0.057 /0.001 = 57.0	0.0049 /0.00095 = 5.15
5th lightest to darkest	0.0078/0.0014 = 5.57	0.0066 /0.001 = 6.6	0.0042 /0.00095 = 4.42
6th lightest to darkest	0.0077/0.0014 = 5.50	0.0062 /0.001 = 6.2	0.0040 /0.00095 = 4.21
7th lightest to darkest	0.0075/0.0014 = 5.35	0.0060 /0.001 = 6.0	0.00352/0.00095 = 3.70
8th lightest to darkest	0.0074/0.0014 = 5.28	0.0053 /0.001 = 5.3	0.00343/0.00095 = 3.61
9th lightest to darkest	0.0065/0.0014 = 4.64	0.0051 /0.001 = 5.1	0.00308/0.00095 = 3.24
10th lightest to darkest	0.0063/0.0014 = 4.5	0.00484/0.001 = 4.84	0.0030 /0.00095 = 3.15
11th lightest to darkest	0.006 /0.0014 = 4.28	0.0046 /0.001 = 4.6	0.00255/0.00095 = 2.68
12th lightest to darkest	0.0047/0.0014 = 3.36	0.0033 /0.001 = 3.3	0.00246/0.00095 = 2.57
13th lightest to darkest	0.0044/0.0014 = 3.14	0.0029 /0.001 = 2.9	0.0022 /0.00095 = 2.31
14th lightest to darkest	0.0042/0.0014 = 3.00	0.0027 /0.001 = 2.7	0.00123/0.00095 = 1.29

TABLE VI.—DISTRIBUTION SERIES.

Ratios showing the relation of the brilliancy of objects in the surrounding field to the surface brightness at the point of work for Positions I, II, III, and IV for the direct, semi-indirect, and indirect systems used.

Position of observer	Ratio	Direct system	Semi-indirect system	Indirect system
I	Lightest to test card	1000/0.00308 = 324,674	0.710 /0.003 = 236.7	0.138 /0.00299 = 46.0
	Lightest to reading page	1000/0.004 = 250,000	0.710 /0.0039 = 182.0	0.138 /0.00431 = 32.0
	2nd lightest to test card	0.3816/0.00308 = 123.9	0.093 /0.003 = 31.0	0.0715 /0.00299 = 24.0
	2nd lightest to reading page	0.3816/0.004 = 95.3	0.093 /0.0039 = 24.0	0.0715 /0.00431 = 16.5
	3rd lightest to test card	0.0517/0.00308 = 16.8	0.059 /0.003 = 29.7	0.066 /0.00299 = 22.0
	3rd lightest to reading page	0.0517/0.004 = 12.9	0.059 /0.0039 = 15.0	0.066 /0.00431 = 15.0
II	Lightest to test card	1000/0.00506 = 197,628	0.710 /0.00453 = 156.7	0.138 /0.0046 = 30.0
	Lightest to reading page	1000/0.0068 = 147,059	0.710 /0.00726 = 97.8	0.138 /0.00792 = 17.0
	2nd lightest to test card	0.3816/0.00506 = 75.4	0.093 /0.00453 = 20.5	0.0715 /0.0046 = 15.5
	2nd lightest to reading page	0.3816/0.0068 = 56.0	0.093 /0.00726 = 12.8	0.0715 /0.00792 = 9.0
	3rd lightest to test card	0.0517/0.00506 = 10.2	0.059 /0.00453 = 13.0	0.066 /0.0046 = 14.3
	3rd lightest to reading page	0.0517/0.0068 = 7.6	0.059 /0.00726 = 8.0	0.066 /0.00792 = 8.0
III	Lightest to test card	1000/0.0055 = 181,818	0.710 /0.00462 = 154.0	0.138 /0.00453 = 30.4
	Lightest to reading page	1000/0.00704 = 142,055	0.710 /0.0077 = 92.0	0.138 /0.00594 = 23.0
	2nd lightest to test card	0.3816/0.0055 = 69.0	0.093 /0.00462 = 26.0	0.0715 /0.00453 = 15.8
	2nd lightest to reading page	0.3816/0.00704 = 54.0	0.093 /0.0077 = 12.0	0.0715 /0.00594 = 12.0
	3rd lightest to test card	0.0517/0.0055 = 9.0	0.059 /0.00462 = 12.8	0.066 /0.00453 = 12.0
	3rd lightest to reading page	0.0517/0.00704 = 0.7	0.059 /0.0077 = 7.7	0.066 /0.00594 = 11.0
IV	Lightest to test card	0.0063/0.0066 = 0.954	0.00484/0.00475 = 1.019	0.00484/0.00453 = 1.068
	Lightest to reading page	0.0066/0.0063 = 1.047	0.00475/0.00484 = 0.785	0.00453/0.00484 = 0.936
	2nd lightest to test card	0.0014/0.0066 = 0.212	0.010 /0.00475 = 0.0210	0.00095/0.00453 = 0.209
	2nd lightest to reading page	0.0014/0.0063 = 0.222	0.010 /0.00484 = 0.00207	0.00095/0.00484 = 0.196

TABLE VII.—DISTRIBUTION SERIES.

Showing the effect on loss of efficiency of varying the observer's position in the room, or the number of light sources primary and secondary, in the field of vision. At Position I, six light fixtures were in the field of vision; at Position II, four light fixtures; at Position III, two light fixtures; and at Position IV, no light fixtures.

Position of observer	Lighting system	Watts	Volts	Intensity foot-candles Hori-zontal	Verti-cal	45°	Time	Maximal distance at which test object can be seen clear	Work-ing distance	Total time clear	Total time blurred	Total time clear ÷ total time blurred	Ratios reduced to comm. standard
I.	Indirect.....	800	107	5.2	1.36	3.5	9 A.M.	84.5	67.5	135	45	3.0	3.5
							12 M.	84.5	67.5	132	48	2.75	3.2
	Semi-indirect	760	107	5.8	1.45	4.0	9 A.M.	80.5	68.5	142	38	3.73	3.5
							12 M.	79.5	68.5	92	88	1.04	0.97
	Direct	880	107	4.2	1.41	2.6	9 A.M.	81.0	68.0	139	41	3.39	3.5
							12 M.	78.0	68.0	71	109	0.65	0.67
II.	Indirect.....	800	107	5.1	1.98	4.2	9 A.M.	86.5	74.0	141	39	3.61	3.5
							12 M.	86.5	74.0	139	41	3.39	3.28
	Semi-indirect	760	107	6.1	2.5	4.7	9 A.M.	87.0	75.0	138	42	3.28	3.5
							12 M.	87.0	75.0	123	57	2.19	2.2
	Direct	880	107	4.65	2.75	4.4	9 A.M.	87.0	75.0	134	46	2.91	3.5
							12 M.	84.0	75.0	99	81	1.22	1.46
III.	Indirect.....	800	107	3.9	2.1	4.0	9 A.M.	84.0	70.0	130	50	2.6	3.5
							12 M.	84.0	70.0	127	53	2.4	3.23
	Semi-indirect	760	107	5.0	2.6	5.4	9 A.M.	84.0	69.0	131	49	2.67	3.5
							12 M.	84.0	69.0	122	58	2.1	2.73
	Direct	880	107	4.0	2.9	4.6	9 A.M.	83.5	70.0	148	32	4.6	3.5
							12 M.	83.0	70.0	137	43	3.8	2.41
IV.	Indirect.....	800	107	2.9	2.1	3.6	9 A.M.	84.0	70.0	139	41	3.39	3.5
							12 M.	84.0	70.0	137	43	3.18	3.27
	Semi-indirect	760	107	3.4	3.0	4.4	9 A.M.	83.5	70.5	139	41	3.39	3.8
							12 M.	83.5	70.5	132	48	2.75	2.83
	Direct	880	107	3.0	3.4	4.5	9 A.M.	82.0	69.0	119	61	1.95	3.5
							12 M.	81.0	69.0	108	72	1.5	2.7

As was also stated in our former paper our next step in this division of the work will be to determine by using reflectors of different degrees of opacity the effect on loss of efficiency when the light is distributed to the plane of work both by the direct and indirect principles of lighting. That is, reflectors of different densities: prismatic, alba, opal lux, totally opaque, etc., will be used turned up and down. In each case the installation will be made with special reference to giving the best results obtainable for the particular type of unit employed; and the factors: evenness of illumination, diffuseness of light, the angle at which the light falls on the work, and the evenness of surface brightness, will be varied separately in turn and the effect on loss of efficiency will be determined. Moreover, if it is found that the factors in question cannot be studied in sufficient detail in the concrete lighting situation, the work will be supplemented by more abstract investigations. The results of this series of tests should give us among other things, for example, a still better idea of what amount of brightness difference the eye is adapted to stand, and the comparative effect of different ratios of surface brightness on loss of efficiency.

INTENSITY SERIES.

In the work of the preceding paper we had undertaken to determine the most favorable intensities for the three types of artificial lighting we had used in the distribution series, and the effect of varying intensity with the particular grouping of distribution factors represented in each case. As was stated in the introduction of the present paper, this work was completed for the direct and semi-indirect systems but not for the indirect. For the semi-indirect installation it will be remembered that the eye fell off heavily in efficiency for all intensities with the exception of a very narrow range on either side of 2.2 foot-candles, measured at the point of work with the receiving test plate of the photometer in the horizontal plane. For the direct installation no intensity could be found for which the eye did not lose a great deal in efficiency as the result of work. For the indirect installation, however, as the following data will show, a comparatively wide range of intensity may be used without the eye suffering

any considerable loss of efficiency as the result of three hours of continuous work.

The tests were made in the same room, with the same fixtures, and in general, with the same conditions of installation and methods of working as were described in the work on the distribution factors. To secure the various degrees of intensity needed, lamps of different wattage were employed. These were selected from a series of tungsten lamps ranging from 15 to 100 watts. In order to keep the distribution factors as nearly constant as possible for a given type of system, the lamps used in making the test for that type of system were all of one wattage, *i. e.,* were all 15's, 25's, 40's, 60's or 100's.

For the indirect system the total range of intensity employed is shown by the following figures. The series was begun with 25-watt lamps, and consisted of 25, 40, 60, and 100-watt lamps. For the 25 watt lamps the photometer reading at the point of work with the receiving test plate in the horizontal plane showed 1.33 foot-candles of light; with the receiving test plate in the vertical plane, 0.39 foot-candle; and with the receiving test plate in the 45 deg. plane, 0.87 foot-candle. For the 100-watt lamps 5.2 foot-candles were obtained with the receiving test plate in the horizontal plane; 1.36 foot-candles with the test plate vertical; and 3.5 foot-candles with the test plate inclined 45 deg. The tests for loss of efficiency[15] showed probably a slight advantage for the 25-watt lamps, although the difference in result for the different intensities is sufficiently near in value to the mean variation of the test as to be scarcely worthy of consideration.

As was the case for the direct and semi-indirect installations, the following specification was made of the illumination effects produced by the indirect installation. (1) Illumination measure-

[15] In conducting these tests it was found necessary to allow a period of adaptation without work, to the illumination of the room before the first test was taken. If this were not done, especially in case of the lower intensities of lights used, the changing sensitivity of the eye to the intensity of light employed, produced a noticeable change in the visual acuity between the times the tests before and after work were taken. Since the distance of the test card was kept the same for the two tests, this change in the visual acuity tended to influence the ratio, time clear to time blurred. To determine the length of time needed under a given intensity of light to insure a constant acuity, so far as adaptation is concerned, preliminary tests were made as follows. The acuity of the observer was taken every 3 minutes until no noticeable change was found. This length of time was then always allowed for that observer as an adaptation period prior to the loss of efficiency test conducted for the given intensity of illumination.

ments were made for the highest intensity employed at the 66 stations in the test room. These measurements were made in the way described in the preceding section. For the other intensities used, measurements were made at nine representative stations to show in a general way the order of magnitude of reduction produced by using the lamps of lower wattage. (2) Brightness measurements were made of the prominent objects in the room, such as the test card, the book of the observer, and all surfaces showing very high or very low brilliancy for all of the intensities.

In Table VIII are given the illumination measurements at the 66 stations for the highest wattages used, made with the receiving test plate of the photometer in the horizontal, vertical, and 45 deg. planes. Tables IX and X show the illumination measurements at the nine representative stations for the other wattages employed in the series. The order of magnitude of reduction of the illumination of the room produced by using the lamps of lower wattage conforms pretty closely in each case, it will be observed, to the simple ratio of the wattages employed. (See foot-note to Table XII, p. 472.) As was the case for the semi-indirect system, noted in the preceding paper, socket extenders had to be used with the 25 and 40-watt lamps. That is, without the extenders these lamps, owing to their smaller size, came so low in the reflector as to change the distribution effects given by reflectors. For example, without the socket extenders for these shorter lamps, the spot of light on the ceiling was made smaller and correspondingly more brilliant. It was thought advisable to determine whether this comparatively small change in illumination effects would cause any difference in the eye's ability to hold its efficiency for a period of work. In the specification of illuminating effects, therefore, measurements have been made for the 25 and 40-watt lamps both with and without socket extenders. In Table IX illumination measurements for the 25 and 40-watt lamps are given with socket extenders, and in Table X illumination measurements for these lamps are given without socket extenders. In Table XI are given the brightness measurements for the indirect installation for the different intensities used, both with and without socket extenders for the 25 and 40-watt lamps.

The points at which the measurements were taken are indicated by the letters A, B, C, D, E, F, etc., see Fig. 4, p. 452b. In Table XII are given the prominent brightness ratios for the different intensities used. Obviously an important point of comparison for the purposes of this investigation is the ratios with and without socket extenders for the 25 and 40-watt lamps.

TABLE VIII.—INTENSITY SERIES.

Showing the illumination measurements in foot-candles for each of the 66 stations represented in Fig. 1 for the indirect system used.

Station	Horizontal	Vertical	45°	Station	Horizontal	Vertical	45°
1	1.22	—	—	34	4.0	1.46	3.1
2	1.26	—	—	35	5.4	1.65	4.9
3	1.32	—	—	36	5.3	1.65	4.0
4	1.47	—	—	37	5.8	1.82	4.0
5	2.2		—	38	5.4	1.72	3.8
6	2.95	—	—	39	4.0	1.43	3.0
7	2.9	—	—	40	2.3	—	—
8	3.0	—	—	41	2.1	—	—
9	2.2	—	—	42	3.5	1.36	2.8
10	1.35	—	—	43	5.0	1.78	3.9
11	1.66	—	—	44	5.2	1.88	4.3
12	2.7	0.47	1.43	45	5.2	1.93	4.2
13	4.1	0.42	1.96	46	5.2	1.86	4.1
14	4.4	0.47	2.3	47	3.6	1.33	2.9
15	4.5	0.47	2.3	48	3.7	1.74	3.3
16	4.1	0.48	2.1	49	4.8	2.1	4.0
17	3.15	0.46	1.6	50	4.9	2.1	4.1
18	2.2	0.47	1.63	51	5.0	2.15	4.35
19	2.5	—	—	52	4.7	1.93	4.0
20	3.4	0.86	2.2	53	3.6	1.41	3.0
21	4.6	0.94	3.0	54	2.8	1.5	2.9
22	4.8	1.07	2.9	55	3.9	1.94	3.75
23	5.1	1.1	2.9	56	4.6	2.1	4.4
24	5.0	1.04	3.0	57	4.5	2.2	4.4
25	3.5	0.75	2.1	58	4.0	2.0	4.0
26	2.2	—	—	59	2.9	1.76	3.1
27	2.4	—	—	60	2.6	1.66	2.9
28	3.7	1.12	2.5	61	3.1	1.9	3.5
29	5.2	1.48	3.4	62	3.2	2.1	3.7
30	5.4	1.4	3.6	63	3.0	2.2	3.5
31	5.2	1.24	3.6	64	3.1	1.93	3.4
32	5.0	1.33	3.4	65	2.25	1.54	2.6
33	3.7	1.22	2.6	66	1.35	—	—
				Average	3.61	1.48	3.3

TABLE IX.—INTENSITY SERIES.

Showing the illumination measurements in foot-candles at nine representative stations for the different intensities used for the indirect system. Socket extenders used with the 40 and 25-watt lamps.

Station	Horizontal				Vertical				45°			
	800	480	320	200	800	480	320	200	800	480	320	200
Card	5.2	3.0	1.7	1.33	1.36	0.765	0.49	0.39	3.5	1.97	1.08	0.87
12	2.7	1.63	0.97	0.65	0.47	0.265	0.18	0.12	1.43	0.83	0.48	0.44
16	4.1	2.2	1.32	1.11	0.52	0.33	0.24	0.14	2.1	1.22	0.66	0.6
31	5.2	2.7	1.84	1.45	1.24	0.77	0.51	0.47	3.6	1.95	1.16	1.01
34	4.0	2.25	1.21	1.0	1.46	0.79	0.52	0.49	3.1	1.63	0.89	0.78
39	4.0	2.2	1.6	0.83	1.43	0.725	0.51	0.37	3.0	1.57	1.04	0.64
45	5.2	2.75	1.94	1.28	1.93	0.99	0.58	0.53	4.2	2.18	1.43	1.0
54	2.8	1.48	1.16	0.68	1.5	0.82	0.63	0.41	2.9	1.51	1.23	0.68
58	4.0	2.1	1.3	1.09	2.0	0.94	0.64	0.52	4.0	2.2	1.3	0.98
Ave.	3.61	2.16	1.44	0.9	1.32	0.89	0.59	0.37	3.3	1.98	1.32	0.83

TABLE X.—INTENSITY SERIES.

Showing the illumination measurements in foot-candles at nine representative stations for the different intensities used for the indirect system. No socket extenders used with the 40 and 25-watt lamps.

Station	Horizontal				Vertical				45°			
	800	480	320	200	800	480	320	200	800	480	320	200
Card	5.2	3.0	1.48	1.16	1.36	0.765	0.407	0.37	3.5	1.97	0.95	0.76
12	2.7	1.63	0.84	0.5	0.47	0.265	0.139	0.99	1.43	0.83	0.44	0.282
16	4.1	2.2	1.01	0.96	0.52	0.33	0.143	0.14	2.1	1.22	0.5	0.48
31	5.2	2.7	1.48	1.3	1.24	0.77	0.462	0.39	3.6	1.95	1.0	0.86
34	4.0	2.25	0.99	1.0	1.46	0.79	0.5	0.45	3.1	1.63	0.84	0.8
39	4.0	2.2	1.63	0.78	1.43	0.725	0.44	0.36	3.0	1.57	0.98	0.6
45	5.2	2.75	1.62	1.18	1.93	0.99	0.52	0.48	4.2	2.18	1.31	0.98
54	2.8	1.48	1.03	0.63	1.5	0.82	0.61	0.41	2.9	1.51	1.18	0.65
58	4.0	2.1	1.11	0.87	2.0	0.94	0.54	0.42	4.0	2.2	1.11	0.83

The results of the tests for the intensity series for the indirect system are given in Table XIII. Three hours was selected as the period of work in all of these experiments. The tests were taken only as Position I (see Fig. 1, p. 452a), the position, it will be remembered, at which six of the fixtures were in the field of view. It will be noted that there is practically no difference in the loss of efficiency of the eye for the different intensities of illumination when socket extenders were used for the shorter lamps. When socket extenders were not used for these lamps, quite a little loss of efficiency was experienced. This loss, moreover, was considerably greater for the shorter 25-watt lamps than for the 40-watt

lamps. Since the prominent variable in this case was intrinsic brilliancy of the ceiling spot above the reflector, the increased loss of efficiency can probably be ascribed primarily to this cause; or more comprehensively stated perhaps, to the change in the magnitude of the brightness differences that were present in the field of vision. For example, the ratio, lightest to darkest for the 100-watt lamps was 145; it was 133 for the 60-watt lamps; 142 for the 40-watt lamps with socket extenders; and 135 for the 25-watt lamps with socket extenders. For the 40-watt lamps without socket extenders, however, this ratio was raised to 326, and for the 25-watt lamps without socket extenders it was raised to 374. Similar changes were also made in the other ratios: lightest to test card, lightest to reading page, etc., as may be seen by inspecting Table XII.

TABLE XI.—INTENSITY SERIES.

Showing the brightness measurements in candlepower per square inch for the different intensities used for the indirect system at points indicated by the letters A, B, C, D, etc., see Fig. 4.

Surface measured	800 watts	480 watts	320 watts: With socket extenders	320 watts: Without socket extenders	200 watts: With socket extenders	200 watts: Without socket extenders
A	0.138	0.0704	0.0539	0.088	0.0352	0.0748
B	0.0715	0.0385	0.0252	0.0231	0.0165	0.0187
C	0.066	0.0352	0.0244	0.022	0.0159	0.0165
D	0.0022	0.00097	0.00079	0.00059	0.00064	0.0004
E	0.0030	0.000163	0.00119	0.0007	0.00084	0.00057
F	0.00123	0.000401	0.00035	0.00022	0.00032	0.00018
G	0.0049	0.00169	0.00145	0.00101	0.00128	0.00084
H	0.0040	0.00163	0.00129	0.00092	0.0011	0.00072
I	0.0042	0.00158	0.00127	0.0009	0.0011	0.00068
J	0.00095	0.00053	0.00038	0.00027	0.00026	0.0002
K	0.00255	0.00123	0.00088	0.00088	0.00074	0.00064
L	0.00246	0.00121	0.00085	0.00079	0.00066	0.00046
M	0.00352	0.00158	0.00106	0.00097	0.00052	0.0007
N	0.00272	0.00101	0.00076	0.00061	0.00066	0.00044
O	0.00343	0.00128	0.00076	0.00028	0.00055	0.00019
P	0.00308	0.00119	0.00067	0.00027	0.00041	0.00018
X	0.00299	0.00154	0.00109	0.0008	0.00074	0.00059
Reading page horizontal	0.0088	0.00405	0.00281	0.0022	0.00198	0.0016
Reading page 45° position	0.00431	0.00273	0.00167	0.00154	0.00117	0.0009

TABLE XII.—INTENSITY SERIES.

Showing some prominent ratios of surface brightness for the different intensities used for the indirect system. An important point of comparison for the purpose of this investigation is the ratios with and without socket extenders.[16]

Ratio	800 watts	480 watts	320 watts With socket extenders
Lightest to darkest	0.138 /0.00095 = 145.0	0.0704/0.00053 = 133.0	0.0539/0.00038 = 142.0
Lightest to test card	0.138 /0.00299 = 46.0	0.0704/0.00154 = 45.0	0.0539/0.00109 = 49.0
Lightest to reading page	0.138 /0.00431 = 32.0	0.0704/0.00273 = 26.0	0.0539/0.00167 = 32.0
2nd lightest to darkest	0.0715/0.00095 = 75.0	0.0385/0.00053 = 72.6	0.0252/0.00038 = 66.0
2nd lightest to test card	0.0715/0.00299 = 24.0	0.0385/0.00154 = 25.0	0.0252/0.00109 = 23.0
2nd lightest to reading page	0.0715/0.00431 = 16.5	0.0385/0.00273 = 14.0	0.0252/0.00167 = 15.0
3rd lightest to darkest	0.066 /0.00095 = 66.3	0.0352/0.00053 = 66.0	0.0244/0.00038 = 64.0
3rd lightest to test card	0.066 /0.00299 = 22.0	0.0352/0.00154 = 22.0	0.0244/0.00109 = 22.0
3rd lightest to reading page	0.066 /0.00431 = 15.0	0.0352/0.00273 = 12.9	0.0244/0.00167 = 14.6

Ratio	320 watts Without socket extenders	200 watts With socket extenders	200 watts Without socket extenders
Lightest to darkest	0.088 /0.00027 = 326.0	0.0352/0.00026 = 135.0	0.0748/0.0002 = 374.0
Lightest to test card	0.088 /0.0008 = 110.0	0.0352/0.00074 = 47.0	0.0748/0.00059 = 127.0
Lightest to reading page	0.088 /0.00154 = 57.0	0.0352/0.00117 = 30.0	0.0748/0.0009 = 83.0
2nd lightest to darkest	0.0231/0.00027 = 85.5	0.0165/0.00026 = 63.5	0.0187/0.0002 = 93.5
2nd lightest to test card	0.0231/0.0008 = 28.9	0.0165/0.00074 = 22.3	0.0187/0.00059 = 31.7
2nd lightest to reading page	0.0231/0.00154 = 15.0	0.0165/0.00117 = 14.0	0.0187/0.0009 = 20.8
3rd lightest to darkest	0.022 /0.00027 = 81.5	0.0159/0.00026 = 61.0	0.0165/0.0002 = 82.5
3rd lightest to test card	0.022 /0.0008 = 27.5	0.0159/0.00074 = 21.5	0.0165/0.00059 = 28.0
3rd lightest to reading page	0.022 /0.00154 = 14.2	0.0159/0.00117 = 13.6	0.0165/0.0009 = 18.3

[16] Theoretically considered, the above ratios: lightest to darkest, lightest to test card, lightest to reading page, etc., should be approximately the same for all of the wattages, if the lamps sustain the same relation to the reflector, to the ceiling, etc. A certain unevenness in these ratios will be noted, however, even when socket extenders were used with the 25 and 40-watt lamps. This is no more than is to be expected because socket extenders of only one length could be obtained, and these did not give the same relation of lamp to reflector for the 25 as for the 40-watt lamp, nor the same relation for either of these lamps as was obtained for the 60 and 100-watt lamps. Obviously too the 60-watt lamps did not sustain the same relation to the reflectors as did the 100-watt lamps.

TABLE XIII.—INTENSITY SERIES.

Showing the effect on the efficiency of the eye of varying the intensity of light in an indirect system composed of 8 units, clear tungsten lamps.

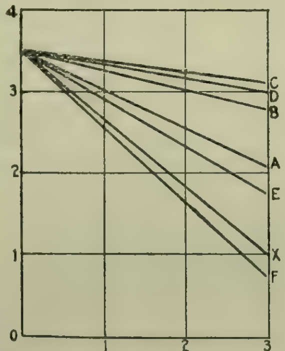
Watts		Foot-candles: Horizontal	Foot-candles: Vertical	Foot-candles: 45°	Time	Maximal distance at which test object can be seen clear	Working distance	Total time clear	Total time blurred	Total time clear ÷ total time blurred	Ratios reduced to common standard
800		5.2	1.36	3.5	9 A.M.	84.5	67.5	135	45	3.0	3.5
					12 M.	84.5	67.5	132	48	2.75	3.2
480		3.0	0.765	1.97	9 A.M.	82.5	65.0	150	30	5.0	3.5
					12 M.	82.0	65.0	148	32	4.6	3.22
320	With socket extenders ..	1.7	0.49	1.08	9 A.M.	81.0	66.0	140	40	3.5	3.5
					12 M.	81.0	66.0	137	43	3.18	3.18
320	Without socket extenders	1.48	0.407	0.95	9 A.M.	79.0	64.0	145	35	4.1	3.5
					12 M.	77.0	64.0	138	42	3.29	2.7
200	With socket extenders ..	1.33	0.39	0.87	9 A.M.	79.0	64.0	122	58	2.1	3.5
					12 M.	79.0	64.0	120	60	2.0	3.3
200	Without socket extenders	1.16	0.37	0.76	9 A.M.	78.0	62.0	149	31	4.8	3.5
					12 M.	76.0	62.0	135	45	3.0	2.1

CHART II.—Intensity Series.

Showing a comparison of the effect on the efficiency of the eye of varying the intensity of light for the four installations of lighting used: the indirect, semi-indirect, and direct systems, 8 lamps; and the direct system, 16 lamps.[17]

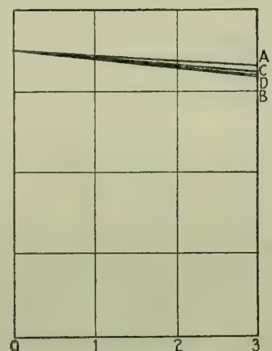
Lighting system: Semi-indirect

	Watts	Volts	Foot-candles Horizontal	Foot-candles Vertical	Foot-candles 45°
A	200	107	1.6	0.45	1.15
B	200	110	1.72	0.484	1.29
C	320	107	2.2	0.58	1.52
D	320	110	2.31	0.62	1.61
E	480	107	3.3	0.94	2.4
F	800	107	6.8	1.82	4.5
X	760	107	5.8	1.45	4.0



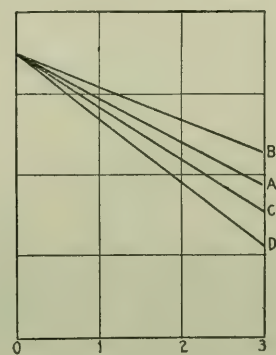
Lighting system: Indirect

	Watts	Volts	Foot-candles Horizontal	Foot-candles Vertical	Foot-candles 45°
A	200	107	1.33	0.39	0.87
B	320	107	1.7	0.49	1.08
C	480	107	3.0	0.765	1.97
D	800	107	5.2	1.36	3.5



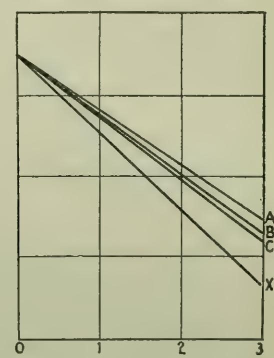
Lighting system: Direct (8 lamps)

	Watts	Volts	Foot-candles Horizontal	Foot-candles Vertical	Foot-candles 45°
A	120	107	0.64	0.32	0.49
B	200	107	1.16	0.45	0.85
C	320	107	1.97	0.65	1.39
D	480	107	2.6	1.02	2.0



Lighting system: Direct (16 lamps)

	Watts	Volts	Foot-candles Horizontal	Foot-candles Vertical	Foot-candles 45°
A	240	107	1.23	0.54	0.935
B	365	107	1.6	0.6	1.33
C	400	107	1.86	0.8	1.46
X	880	107	4.2	1.41	2.6

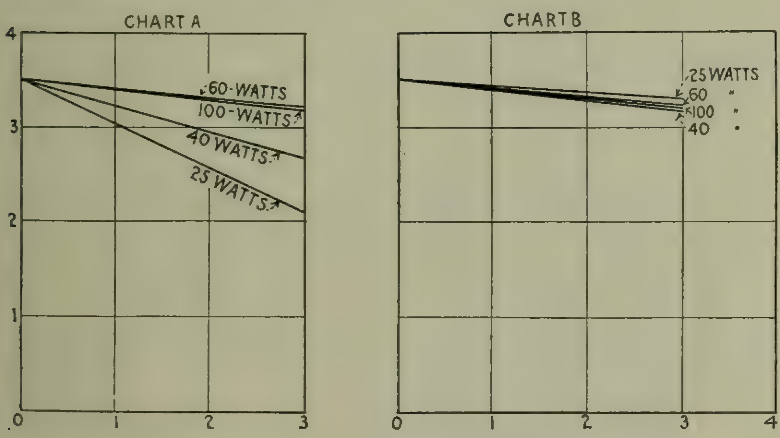


[17] For a full specification of the illumination effects, brightness and illumination measurements, brightness ratios, etc., produced by the direct and semi-indirect systems for the different wattages, see the previous paper (op. cit., pp. 428-441).

A graphic representation of the results for the indirect system with socket extenders is given in Chart II. In this chart loss of efficiency is plotted against time of work in the manner described in the preceding section. For the sake of comparison results are shown also on this chart for the direct and semi-indirect systems. A graphic representation has further been made of the results for the indirect system with and without socket extenders. This is shown in Chart III.

CHART III.—Intensity Series.

Showing the effect on loss of efficiency of changing the height of the light source in the reflector of the indirect lighting fixtures. The effect on surface brightness is primarily to change the area and surface brilliancy of the spot of light thrown on the ceiling. Chart A shows the results when height of source in the reflector is changed; Chart B, the results when the height is kept approximately constant.



EYE SHADE SERIES.

This series of experiments has been conducted for the following reasons. (1) In general two methods are used to protect the eye from the source of light, eye shades and lamp shades. It is desirable to know whether the eye is protected equally well by both; and if the eye shade can be substituted for the lamp shade, what type of shade would best serve the purpose. (2) And the statement has been made to us many times that with an eye shade the three systems of artificial lighting we have used should give equally good results; and results, moreover, as good

as those given by the indirect system without an eye shade. There are in general two classes of eye shades, the translucent and opaque. Up to this time we have confined our work to the opaque shade. So far as we know it is customary to make the opaque shade with a dark lining. This kind of lining is employed probably because of some notion that it is restful to the eye to darken as much of the field of vision as is possible.[18]

The tests were begun with the opaque shade with the dark lining. What we found as the result of these tests was somewhat in contradiction to the predictions that had been made. The shade did give pretty nearly the same results for the three systems; but it did this, contrary to prediction, by improving the direct and semi-indirect systems and making worse by almost an equal amount the indirect system. That is, protected by the opaque shade, the eye lost in efficiency for the three systems by an amount somewhere near the mean of the losses experienced by it for the three systems without a shade. Nor is this result surprising when one reflects upon the conditions imposed upon the eye by an opaque shade with a dark lining. While it protects the eye from the sources of light, such a shade does not by any means eliminate harmful brightness differences in the field of vision. It in fact creates for the eye a very unnatural brightness relation, *i. e.,* it renders the whole upper half of the field of vision dark in sharp contrast with the brightly lighted lower half. The direct effect of this is a strong brightness induction (physiological) over the lower half of the field of vision which manifests itself to the observer by causing glare in surfaces that have no glare, and by increasing the glare in surfaces in which glare is already present. This, it is scarcely necessary to point out, operates against the discrimination of detail and puts the eye under strain to see its objects clearly. Moreover, the unusual and strongly irregular character of the image formed on the retina probably also sets up a warfare in the incentives given to the muscles which adjust the eye. That is, the upper half of the field of vision is dark and presents no detail. The effect of this is probably to exert a tendency to cause the muscular relax-

[18] Another popular view might be, so far as protection to the eye is concerned, to regard the opaque eye shade as the analogue of the opaque or perhaps the indirect lamp reflector and the translucent shade as the analogue of the semi-indirect reflector.

ation characteristic of the darkened field of vision. The lower half of the field is light and filled with detail. The incentive here is towards the best possible adjustment of the eye for the discrimination of detail in the objects viewed, while the rim of the shade, the sharply marked boundary between the dark and light halves of the field of vision and much nearer to the eye than the objects viewed,[19] serves as a constant and consciously annoying distraction to fixation and accommodation. These complex and somewhat contradictory impulses given to the muscles of the eye might very well, and doubtless do cause an excessive and unnatural loss of energy and efficiency in case of the prolonged adjustment of the eye needed for a period of work.

Early in the course of the tests it occurred to us that we might render the brightness distribution in the field of view presented to the eye wearing a shade more natural, and thereby improve the effect of the shade on the eye, by employing a white instead of a dark lining. By using a matt white paper[20] with a reflection coefficient of about 75 per cent. for this lining, the following effects were produced. The two halves of the field of vision were rendered much more nearly of equal brightness; the glare in the lower half of the field of vision was very noticeably lessened and the discrimination of detail was correspondingly improved; the upper half of the field of view no longer tended to give to the eye the reflexes of the darkened field of vision; and the rim of the shade did not stand out nearly so distinctly in the field of view to distract accommodation and fixation. The results of the test for loss of efficiency show, moreover, that our surmise with regard to the effect of this change on the eye was correct. The action of the white lining was greatly to improve the ability of the eye to maintain its efficiency for a period of work. As good results were not gotten, however, with the shade for any of the systems as were given by the indirect system without the shade. Since there was a still greater evenness of surface brightness in the field of view in case of the indirect system with the eye shade than without, the question arises why

[19] This rim is about three inches in front of the observer's eye when the shade is in position.

[20] Hering standard white paper was used for this lining. The reflection coefficient of the dark lining was about 6–8 per cent.

at least as good results were not obtained with the shade as without. The answer, we believe, is to be found in terms of the distraction to fixation and accommodation caused by the eye shade even when a light lining was used. For the effect of a shade on the eye even when the most favorable lining is employed is that of a constantly present distracting object with its lower margin not far removed from the center of the field of vision, and much nearer to the eye than are the objects which the observer is called upon to discriminate. It will be noticed also in Table XVII that the results were never so good for either kind of shade for the direct and semi-indirect systems as for the indirect. Since the evenness of surface brightness in the field of view was not very different for the three systems in both cases, this again probably indicates that the evenness of surface brightness is not the only one of the distribution factors that has to be taken into account in studying the effect of different conditions of lighting on the eye.

These tests were made for the same installations that were used in the distribution series. Since the use of the eye shade did not affect the illumination of the room the reader is referred for the illumination measurements to the tables of the distribution series. The distribution of surface brightness in the field of vision, however, was strongly affected. New measurements were made, therefore, of the brightness of the prominent surfaces in the field of vision. The tests were taken at Position I, see Fig. 1, p. 452a The prominent surfaces in the observer's field of vision working in this position were J, K, and L (see Fig. 4, p. 452b); the top of the table carrying test and recording apparatus, immediately in front of the observer and below the level of his eyes; the test card; the reading page in the 45 deg. position; and the white and dark lining of the eye shade as seen by the observer when the shade was in position over his eyes. The measurements of the brightness of the lining of the eye shades as seen by the observer when the shades were in position were made as follows. A surface in front of the observer was made to match in brightness the lining of the shade as it was seen by him. The brightness of this surface was then measured by the method described on page 452. In procuring the match between the comparison surface and

the lining of the shade the series of Hering matt gray papers was employed. This series consists of 50 shades ranging from a white with a reflection coefficient of 75 per cent. to black. Sheets of these differing in brightness were placed in a vertical position at a given distance in front of the observer until an approximate match was made with the lining of the shade. The gradations needed to get the final match were secured by moving the surface to and from the observer and by tilting it at different angles with the line of sight. The former adjustment carried it into parts of the room having different intensities of illumination and the latter turned it so as to receive a greater or less amount of light. In making the brightness measurements, care was taken to have the receiving surface of the photometer arm normal at its central point to the line of sight taken by the observer when the match was made. The results of these measurements are shown in Table XIV. In Table XV are given some of the prominent ratios of surface brightness in the field of vision for the shade with the dark lining; and in Table XVI, some of the prominent ratios for the shade with the white lining. In Table XVII are shown the results for the test for loss of efficiency for the shade with the dark lining; and in Table XVIII for the shade with the white lining. For purposes of comparison the results of the three systems without a shade are repeated. These are given in Table XIX. A graphic representation results of all three tables is given in Chart IV.

TABLE XIV.—EYE SHADE SERIES.

Showing the brightness measurements in candlepower per square inch for the various surfaces in the field of vision for the direct, semi-indirect and indirect systems used when the eyes were shielded in turn by an opaque eye shade with a dark lining, and an opaque eye shade with a white lining.

Surface measured	Direct system	Semi-indirect system	Indirect system
J	0.0014	0.001	0.00095
K	0.0063	0.0046	0.00255
L	0.0042	0.0027	0.00246
Table	0.0029	0.00255	0.00233
Test card	0.00308	0.003	0.00299
Reading page 45° position	0.004	0.0039	0.00431
White lining of eye shade	0.00197	0.00204	0.00207
Dark lining of eye shade	0.000091	0.00011	0.000126

TABLE XV.—EYE SHADE SERIES.

Showing some prominent ratios of surface brightness for the direct, semi-indirect, and indirect systems used when the eyes were shielded by an opaque eye shade with a dark lining.

Ratio	Direct system	Semi-indirect system	Indirect system
Lightest to darkest	0.0063/0.000091 = 69.2	0.0046/0.00011 = 42.0	0.00431/0.000126 = 34.2
Lightest to test card	0.0063/0.00308 = 2.04	0.0046/0.003 = 1.53	0.00431/0.00299 = 1.5
Lightest to reading page	0.0063/0.004 = 1.56	0.0046/0.0039 = 1.2	0.00431/0.00431 = 1.0
Lightest to lining of eye shade	0.0063/0.000091 = 69.2	0.0046/0.00011 = 42.0	0.00431/0.000126 = 34.2

TABLE XVI.—EYE SHADE SERIES.

Showing some prominent ratios of surface brightness for the direct, semi-indirect, and indirect systems used when the eyes were shielded by an opaque eye shade with a white lining.

Ratio	Direct system	Semi-indirect system	Indirect system
Lightest to darkest	0.0063/0.0014 = 3.9	0.0046/0.001 = 4.6	0.00431/0.00095 = 4.5
Lightest to test card	0.0063/0.00308 = 2.04	0.0046/0.003 = 1.53	0.00431/0.00299 = 1.0
Lightest to reading page	0.0063/0.004 = 1.56	0.0046/0.0039 = 1.2	0.00431/0.00431 = 1.0
Lightest to lining of eye shade	0.0063/0.00197 = 3.2	0.0046/0.00204 = 2.25	0.00431/0.00207 = 2.5

TABLE XVII.—EYE SHADE SERIES.

Showing the eye's loss in efficiency as the result of 3 hours of work under the direct, semi-indirect, and indirect systems of lighting employed. (With opaque eye shade with dark lining.)

Lighting system	Watts	Foot-candles Hori-zontal	Verti-cal	45°	Time	Maximal distance at which test object can be seen clear	Working distance	Total time clear	Total time blurred	Total time clear ÷ total time blurred	Ratios reduced to common standard
Indirect	800	5.2	1.36	3.5	9 A.M.	80.0	68	143	37	3.86	3.5
					12 M.	80.0	68	130	50	2.6	2.34
Semi-indirect	760	5.8	1.45	4.0	9 A.M.	80.0	68	126	54	2.33	3.5
					12 M.	79.5	68	110	70	1.55	2.33
Direct	880	4.2	1.41	2.6	9 A.M.	79.0	67	139	41	3.39	3.5
					12 M.	79.0	67	124	56	2.21	2.27

TABLE XVIII.—EYE SHADE SERIES.

Showing the eye's loss in efficiency as the result of 3 hours of work under the direct, semi-indirect, and indirect systems of lighting employed. (With opaque eye shade with white lining.)

Lighting system	Watts	Foot-candles Hori-zontal	Verti-cal	45°	Time	Maximal distance at which test object can be seen clear	Working distance	Total time clear	Total time blurred	Total time clear ÷ total time blurred	Ratios reduced to common standard
Indirect	800	5.2	1.36	3.5	9 A.M.	85.0	68	118	62	1.9	3.5
					12 M.	85.0	68	115	65	1.77	3.18
Semi-indirect	760	5.8	1.45	4.0	9 A.M.	85.0	68	128	52	2.46	3.5
					12 M.	85.0	68	124	56	2.21	3.13
Direct	880	4.2	1.41	2.6	9 A.M.	85.0	70	105	75	1.4	3.5
					12 M.	84.5	70	100	80	1.25	3.07

TABLE XIX.—EYE-SHADE SERIES.

Showing the eye's loss in efficiency as the result of 3 hours of work under the direct, semi-indirect, and indirect systems of lighting employed (No eye shade.)

Lighting system	Watts	Foot-candles Hori-zontal	Verti-cal	45°	Time	Maximal distance at which test object can be seen clear
Indirect	800	5.2	1.36	3.5	9 A.M.	84.5
					12 M.	84.5
Semi-indirect	760	5.8	1.45	4.0	9 A.M.	80.5
					12 M.	79.5
Direct	880	4.2	1.41	2.6	9 A.M.	81.0
					12 M.	78.0

	Working distance	Total time clear	Total time blurred	Total time clear ÷ total time blurred	Ratios reduced to common standard
Indirect	67.5	135	45	3.00	3.5
	67.5	132	48	2.75	3.2
Semi-indirect	68.5	142	38	3.73	3.5
	68.5	92	88	1.64	0.97
Direct	68.0	139	41	3.39	3.5
	68.0	771	109	0.69	0.671

As yet we have not determined the effect of translucent shades on the eye. In attempting to deal in a general way with this class of shades we have the same type of difficulty to face that we have in case of the semi-indirect reflector. That is, we may have shades varying from transparent to opaque, and sharing in the merits and demerits of each extreme. Our judgment would be, however, that it would be very difficult to get a translucent shade that would give as good results as an opaque shade with a light lining; for the translucent shade when made sufficiently opaque to give the needed reduction to the image of the source will darken too much the upper half of the field of vision and thereby simulate too much the condition given by the opaque shade with the dark lining to give the best results for comfortable and efficient seeing. Moreover, from the results that have already been obtained with the opaque shade and from the principles it seems fair to infer from these results, it seems very probable to us that as good effects for seeing should not be expected from the use of

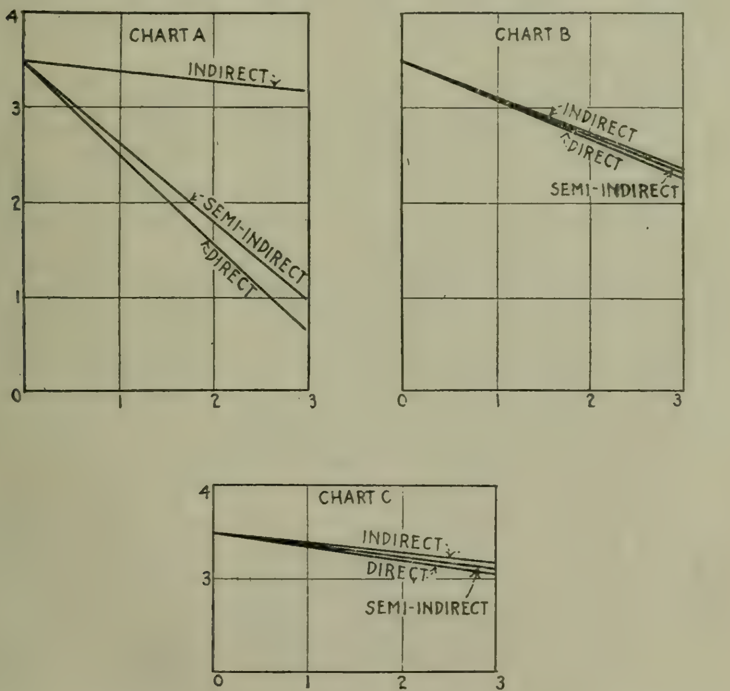
any kind of eye shade as may be gotten from lamp-shades. That is, if we are to secure the best results for seeing, the shade should be put on the lamp, not on the eye.

THE ANGLE AT WHICH THE LIGHT FALLS ON THE WORK.

The object of these experiments was to find out whether the

CHART IV.—Eye Shade Series.

Showing the effect on loss of efficiency of opaque eye shades with dark and with white lining for the installations direct, semi-indirect, and indirect with the same intensity of light at the point of work. Chart A shows results without shade ; Chart B, with shade having dark lining; Chart C· with shade having white lining.



difference in the angle at which the light falls on the work produces an effect on the eye that can be detected by the test we have used for loss of efficiency. For the purpose of this preliminary investigation it was decided to make the general illumination of the room such as to cause the eye little loss of effi-

ciency as the result of the period of work; and to add to that at the point of work a component of light which was less diffuse in order that the amount of light entering the eye would be more dependent upon the angle at which the reading page was held.

The general illumination was obtained from the indirect system used in the work of the preceding sections with lamps totalling 800 watts. The less diffuse component at the point of work was obtained from a 60-watt lamp with a porcelain reflector of the desk lamp type. This lamp was turned into the horizontal position and was placed behind the observer and to the left so that the light came over the left shoulder. When in the position for which the test was taken the tip of the lamp was slightly above the level of the observer's eye, at a distance of 1 meter from the left eye.

The illumination and brightness measurements for the test room illuminated by the indirect system, 800 watts, are given on pp. 469 and 471. These measurements were not greatly changed by the addition of the 60-watt lamp behind the observer. Because of the presence of this lamp, however, the following measurements were added to those given on pp. 469 and 471: the horizontal, vertical, and 45 deg. components of light at the point of work; the brightness of the test card in place for the test; and the brightness of the reading page when held respectively in the positions which gave the least and the greatest amounts of specular reflection. The illumination measurements at the point of work are given in Table XX. The brightness of the test card was 0.00365 cp. per sq. in.; of the reading page in the position that gave the least amount of specular reflection, 0.0059 cp. per sq. in.; and in the position that gave the greatest amount of specular reflection, 0.0077 cp. per sq. in. A mirror surface was used as an aid in locating the position of least and greatest specular reflection. The results of the test for three hours of work done with the reading page in these two positions are also given in Table XX. A graphic representation of the results of this table is shown in Chart V.

THE EFFECT OF DIFFERENT CONDITIONS OF LIGHTING ON THE FIXATION MUSCLES OF THE EYE.

The test we have employed thus far in the conduct of our

work is one designed to show the effect of different conditions of lighting on the ability of the eye to hold its efficiency for clear seeing for a period of three minutes. In itself this test is not

TABLE XX.—THE ANGLE AT WHICH THE LIGHT FALLS ON THE WORK.

Showing the effect on loss of efficiency of the angle at which the light falls on the work.

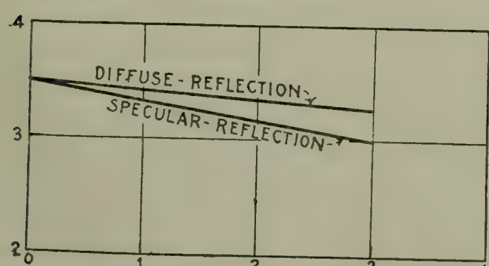
Kind of reflection from reading page during work period	Foot-candles at test-card: Horizontal	Vertical	45°	Time	Maximal distance at which test object can be seen clear
Diffuse	5.3	1.84	3.9	9 A.M.	89
				12 M.	89
Specular	5.3	1.84	3.9	9 A.M.	89
				12 M.	89

	Working distance	Total time clear	Total time blurred	Total time clear ÷ total time blurred	Ratios reduced to common standard
Diffuse.........	73	139	41	3.39	3.5
	73	137	43	3.18	3.27
Specular	73	137	43	3.18	3.5
	73	132	48	2.73	3.0

analytical in principle. The results, as is stated above, are expressed in terms of an aggregate loss of function. The contributive factors may be inferred from the nature of the test, but

CHART V.—THE ANGLE AT WHICH THE LIGHT FALLS ON THE WORK.

Showing the effect on loss of efficiency of the angle at which the light falls on the work.



the test is not in itself designed to separate them out. And indeed it is a question whether any practical good can accrue to the practise of lighting from a knowledge of just what part of

the visual apparatus it is that falls off in function as the result of an unfavorable condition of lighting. Obviously the chief need is to find out what are the conditions that cause the eye to lose its ability to see clearly and to avoid these conditions in planning and installing a lighting system. From the beginning we have had in mind, however, an analysis of effect. Our tests for the sensitivity of the retina showed, for example, that very little, if any, of the difference in results we have gotten for the four types of lighting we have employed can be ascribed to a loss in the efficiency of the retina, or the light sensitive part of the visual apparatus. Three sets of factors are involved in clear seeing: (1) the sensitivity of the eye to colored and white light; (2) the ability to make fine space discriminations which is in part dependent upon our third factor; and (3) accurate fixation and accommodation. Both fixation and accommodation are the result of muscular action. When the muscles lose in tone because of excessive use or by sharing in a general condition or state of the body, the eye loses correspondingly in its power to sustain clear seeing. If, for example, the muscles of accommodation have fallen off in efficiency the lens is no longer held in the adjustment needed to bring the light to a sharp focus on the retina and loss of detail and blurring result; or, if it be the fixation muscles that have suffered the loss, the eyes cannot be continuously held in such a position that the images of the object viewed fall symmetrically on the fovea of each. When this latter condition is present loss of detail results from two causes. (1) The fovea and region immediately surrounding it are the most highly developed parts of the retina and the best fitted for the light and space discriminations needed for clear seeing. Moreover, the refracting media of the eye give the clearest images when the axis of the cone of rays from the object viewed deviates as little as possible, consistent with the mechanism of the eye, from the optic axis. And (2) if the images in the two eyes do not fall more or less symmetrically upon the fovea of each they are not accurately combined into one, and blurring and loss of detail results from the doubling of the objects seen. It is our purpose as fast as possible to isolate the effect of the three systems of lighting we have used on each of the above named factors. In

the work of the present section the effect of these systems on the fixation muscles has been studied.

The doubling of the image seen when the fixation muscles lose their power of co-ordinated action furnishes us with our clue for a test for the loss of efficiency of these muscles. That is, just as blurring and the loss of ability to discriminate detail is taken as the criterion of the loss of acuity of vision, so will the doubling of the image seen be taken as our index of the loss of the co-ordinated action of the fixation muscles. If one were to stare continuously for an interval of time with natural vision at a simple test object, as, for example, a vertical line, doubling might be detected especially if there had been protracted strain or considerable loss of power to co-ordinate. For the purpose of our work, however, greater sensitivity than this would be needed. Obviously sensitivity can be added by putting the eyes under strain to combine their images. When this is done, even when the muscles are fresh, if the object is looked at or fixated for an interval of time it will be seen alternately as one and as two. The proportion or ratio of the time seen as one to the time seen as two can be regulated by the amount of initial strain under which the eyes are put to combine their images. The regulation of this ratio is empirical and of importance; for as is the case with the test for loss of efficiency for clear seeing, the sensitivity of the test depends to a considerable extent upon the initial value that is given to this ratio. The eyes may be put under strain to combine their images by interposing between them and the object viewed weak prisms and so adjusting them and regulating the distance of the object from the eye that with the maximum of effort to see it as one it is seen alternately as one and as two in the proportion desired.[21] This result can be accom-

[21] It would seem that the above principle might be utilized to advantage by the opthalmologist in testing the extrinsic muscles of the eye. The abduction and adduction tests, for example, determine only what the muscles are able to do by momentary effort. Obviously, however, it is not what the muscles are able to do by a momentary effort or jerk that measures their ability to hold the eyes continuously adjusted for work. It is rather their endurance or what they are able to accomplish in an interval of time. An expression may be had for this either for the eyes conjointly or separately by the method described above. That is, the prisms may be put in front of either one or both eyes and the ratio be determined of the time the object is seen as one or as two for whatever interval of time the operator may select. Similarly, it seems to the writers that the time element might be introduced to ad-

(*Continued on next page.*)

plished still more conveniently, however, by using an adaptation of the Brewster stereoscope. In this case a stereograph consisting of two vertical lines exactly alike may be used as the test object. In the stereograph employed in our test the vertical lines were 2.5 cm. long and were printed on the card 4.5 cm. apart or at 2.25 cm. from the center of the card. When this was put in a sliding carrier and was made to approach the eyes, a position was reached at which with the maximum of effort the observer was no longer able to see the two vertical lines as one. They were seen alternately as one and as two. In making the test the hood was removed from the stereoscope so that the eyes were fully exposed to the conditions of illumination that were being tested. The stereoscope was mounted in front of the eyes of the observer in position at the point of work. The distance of the carrier containing the test object from the observer's eyes was adjusted until the proper ratio of time seen as one and time seen as two was obtained. Having determined this position a record was made of the time seen as one and the time seen as two for three minutes at the beginning and the close of work. The ratio of the sum of these intervals may in either case be taken as a measure at that time of the power of the fixation muscles to act in co-ordination for three minutes of continuous effort; and the decrease in this ratio from the beginning to the close of work may be taken as a measure of the loss in that power, sustained as the result of work. In making this test the same recording apparatus was used as was employed in the test for loss of efficiency for clear seeing. That is, the record was traced on a kymograph by means of an electro-magnetic marker and a

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vantage into the visual acuity test used by the ophthalmologist when the cycloplegic is not employed or in cases of post-cycloplegic refraction. Is it, for example, enough to know that the eye has 20/20 acuity or can discriminate a certain standard visual angle by momentary effort? Would it not give a more complete repreentation of the functional condition of the eye to know what it can discriminate clearly through an interval of time; or better still perhaps, for what proportion of an interval of time it can discriminate a certain detail or standard visual angle clearly? For example, just as a fatigued eye may for the moment under the spur of the test overcome the functional results of fatigue, so might small errors of refraction be overcome for the moment by muscular effort, especially in the cases in which the muscles of the eye are unusually strong. But just as the fatigued muscle can not do this through an interval of time, so it would seem that a residual error of refraction might not be so easily masked through an interval of time by means of muscular effort. In short, this form of test is suggested as affording possibly a closer approximation to the conditions and demands imposed upon the eye during a period of work than is afforded by the acuity test based upon the momentary judgment.

telegraph key, and a time line was run beneath the record by means of a Jacquet chronograph registering seconds.

The test for the effect on the fixation muscles of a period of work was made under the same installations, conditions of work, and with the same observers that were used in the distribution series. The test, however, was made at only one of the positions used in that series, namely, the position at which the greatest loss of efficiency was obtained. (See Position I, Fig. 1, p. 452a.) At this point, it will be remembered, six of the lighting

TABLE XXI.—FIXATION MUSCLES SERIES.

Showing the loss of efficiency of the fixation muscles as the result of 3 hours of work under the direct, semi-indirect, and indirect systems of lighting employed.

Lighting system	Watts	Foot-candles Horizontal	Vertical	45°	Time	Distance at which test object is normally seen single
Indirect	800	4.2	0.99	2.5	9 A.M.	18
					12 M.	18
Semi-indirect	760	4.8	0.98	2.6	9 A.M.	18
					12 M.	18
Direct	880	3.9	1.0	1.99	9 A.M.	18
					12 M.	18

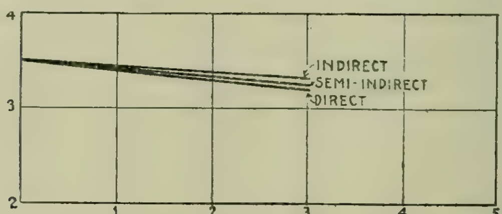
	Working distance	Total time single	Total time double	Total time single ÷ total time double	Ratios reduced to common standard
Indirect	22	142	38	3.7	3.5
	22	140	40	3.5	3.31
Semi-indirect	22	141	39	3.6	3.5
	22	138	42	3.28	3.24
Direct	20	153	27	5.66	3.5
	20	151	29	5.21	3.21

units were in the field of view. The specification of the lighting effects produced by these installations are given on pp. 452a-459 Nothing need be added at this point to these specifications but the brightness of the stereograph or the test object in position for the three systems of lighting, and the illumination measurements at the test card. The brightness measurements are as follows. The brightness of the card, corrected for the absorption of the prisms of the stereoscope was for the direct system 0.00172 cp. per sq. in.; for the semi-indirect system,

0.00163 cp. per sq. in.; and for the indirect system, 0.00167 cp. per sq. in. New illumination measurements were needed at the test card because the card had to be moved closer to the eyes than was the case in the tests for loss of efficiency for clear seeing, which brought it into a region of different illumination. These measurements are given in Table XXI. The results of our tests for loss of efficiency of the fixation muscles for the three systems of lighting are given also in this table. These results show (a) that very little loss of co-ordination is suffered by the fixation muscles as the result of three hours of work under the systems selected; and (b) that there is very little difference in

CHART VI.—Fixation Muscle Series.
Showing the loss of efficiency of the fixation muscles as the result of 3 hours of work under the direct, semi-indirect, and indirect systems of lighting employed.

		Foot-candles		
Lighting system	Watts	Horizontal	Vertical	45°
Indirect	800	4.2	0.99	2.5
Semi-indirect ..	760	4.8	0.98	2.6
Direct	880	3.9	1.0	1.99



the effect for the three systems. Since there is no reason for thinking that the test has not as great sensitivity as the test for loss of efficiency for clear seeing, and since the same observers, conditions of lighting and working were used as in the former tests, it does not seem to us at this time that the loss of efficiency for clear seeing that is sustained under these conditions, shown by the former tests, can be ascribed to any great extent to an effect on the muscles of fixation. In a later report experiments will be described in which the effect on the muscles of accommodation has been studied.

A graphic representation of the results of Table XXI is shown in Chart VI.

THE EFFECT OF MOTION PICTURES ON THE EFFICIENCY OF THE EYE.

The belief that motion pictures subject the eyes to undue strain is too prevalent to need more than mention in passing. All are familiar with the conditions,—the initially dark-adapted and highly sensitized eye, the comparatively brilliant screen with its dark surrounding field, the flickering light, and the shifting and very often unsteady pictures. We have already seen that differences in surface brightness of considerable magnitude in the field of vision cause loss of efficiency and produce discomfort, and we have discussed the causes for these effects. We have nothing further to add to that discussion here. We are, however, facing for the first time in our work the question of the effect upon the eye of a flickering light and lack of steadiness in the object viewed. The following reason is suggested why a flickering or unsteady picture may cause loss of efficiency. The eye is so constituted that when its images lose in clearness or distinctness it is incited to a muscular readjustment to bring about the clearness needed. Ordinarily in seeing, the conditions for loss in clearness come about primarily through the difference in the distance or direction from the eye of the objects which are successively viewed. In motion pictures, however, the changing clearness of the objects viewed is not due to any change in their distance or direction from the eye; nor to anything in fact which the readjustment of the eye can remedy to any considerable degree. The effort expended, therefore, is of little avail for seeing, if, indeed, the new setting of the parts is not a detriment to clear seeing and a condition which in turn must be corrected. This should, and doubtless does, lead to muscular strain and loss of efficiency. It was decided, therefore, to make an explorative investigation to determine whether there is an effect of motion pictures on the eye which can be detected by our test for loss of efficiency. The tests were conducted in a local theater, selected primarily because of the favorable conditions that prevailed. The definition at the screen was good and the pictures were unusually steady and free from flicker. The conditions were, we think, fairly representative of what is found in the better class of motion picture houses.

The tests were taken immediately before and after two hours of observation of the pictures. During the exhibition the observer sat directly in front of the center of the screen. The observation was made at successive times at three distances from the screen,—in the front, middle, and the back of the house. These positions were respectively 25, 48, and 71 ft. (7.62, 14.6, and 21.6 m.) from the screen. The room in which the pictures were shown was 78 ft. (23.7 m.) long and 48 ft. (14.6 m.) wide. The tests were taken in a room 14 ft. (4.2 m.) long, 9 ft. (2.74 m.) wide, 11 ft. (3.35 m.) high, adjoining the stage. The walls and ceiling of this room were of rough plaster, painted a flat white. When taking the test the observer sat facing one of the side walls of the room, 1.5 m. distant. The room was lighted for the purpose of the test by one 100-watt and one 60-watt clear tungsten lamp suspended behind and slightly to the right of the observer when in position for the test, at about 2 ft. (0.6 m.) above the level of his eyes. The source of light was thus entirely out of the field of view and the light fell evenly and without shadow on the test card and the wall in front of the observer. At the point of the test card, the illumination measured with the receiving test plate of the photometer in the horizontal plane was 1.3 foot-candles; in the vertical plane, 1.9 foot-candles; and in the 45 deg. plane, 2.3 foot-candles. The surface brightness of the test card was 0.003256 cp. per sq. in., and that of the wall directly behind the card was 0.002288 cp. per sq. in. The distribution of surface brightness on the wall which the observer faced was very even. At the point of maximum brightness to the right of the observer, as nearly as that point could be located, the brilliancy was 0.00308 cp. per sq. in.; and to the left of the observer, 0.002024 cp. per sq. in.

In order that there might be no intermission between the pictures for changing the films, two projection machines were used. The following is the specification of the apparatus employed as given by the operator.

Type of machine, Powers 6—A Projector.

Lens equipment, 1 pair pearl white condensers, 6½ in. F. L.
1 Bausch and Lomb objective combination, 4¾ in. E. F.

Lamp, 1 10,000-cp. adjustable arc.
Carbons, 5/8 in. cored bio's.
Current, 22 volt a. c. through Halberg transformer.
Line current, 28–30 amperes.
Arc voltage, 45–50 volts.
Length of throw or distance from objective to screen, 72 ft. (21.9 m.)
Screen, sheet muslin sized and coated with flat white alabastine.
Speed of film through machine, 66 ft. 8 in. (20.3 m.) per min.
Number of pictures per 1 ft. (0.3 m.) of film, 16.
Size of picture on film, 3/4 in. (1.9 cm.) high by 15/16 in. (2.38 cm.) wide.
Size of picture on screen, 11 ft. (3.35 m.) high by 14 ft. (4.26 m.) wide.
Approximate brightness of screen with film removed from projector, 3.47 cp. per sq. in.

Exceptional steadiness, it may be said, is given to the movement of the film and, therefore, to the picture in this type of projector by the special type of intermittent movement that is employed. Details of this movement need not be given here. As has already been stated, our reason for making the test in this particular theater was the comparative steadiness of the pictures and the comparative freedom from flicker, that was obtained.

The results of the tests are shown in Table XXII. Quite a great deal of loss of efficiency is shown as the result of two hours of observation. The nearer the observer was to the screen, the greater was this loss found to be. The loss, however, so far as we can tell, is no greater than is caused by steady work under the direct and semi-indirect installations of lighting used in our distribution series. Unfortunately, we have not for the purposes of comparison, results for the same observer for the same length of time of exposure for the two sets of condition. The loss for observer R for two hours observation of the motion pictures was not nearly so great as for three hours of reading from good print and paper, under the direct and semi-indirect systems of lighting. But comparing the results for observer G for two hours of reading from the same type and paper with those for observer R for two hours observation of the pictures the

loss seems to be about the same. That is, our results indicate that while the eyes are strained a great deal by the observation

TABLE XXII.—MOTION PICTURE SERIES.

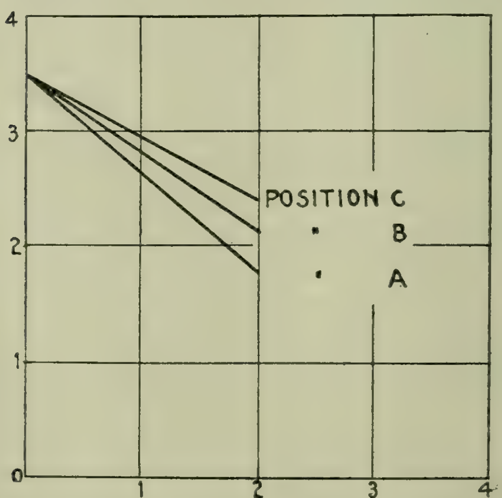
Showing the loss of efficiency of the eye caused by two hours' observation of motion pictures.

Position	Time	Maximal distance at which test object can be seen clear	Working distance	Total time clear	Total time blurred	Total time clear ÷ total time blurred	Ratios reduced to common standard
25 ft. (7.62 m.) from projection screen..	8 P.M.	86.2	70.5	123	57	2.14	3.5
	10 P.M.	86.1	70.5	95	85	1.12	1.79
48 ft. (14.63 m.) from projection screen..	8 P.M.	85.8	71.0	128	52	2.46	3.5
	10 P.M.	85.6	71.0	108	72	1.5	2.13
71 ft. (21.64 m.) from projection screen..	8 P.M.	86.0	69.0	137	43	3.19	3.5
	10 P.M.	86.0	69.0	124	56	2.2	2.42

CHART VII. MOTION PICTURE SERIES.

Showing the loss of efficiency of the eye caused by two hours observation of motion pictures.

Position A .... 25 ft. from projection screen
Position B .... 48 ft. from projection screen
Position C .... 71 ft. from projection screen



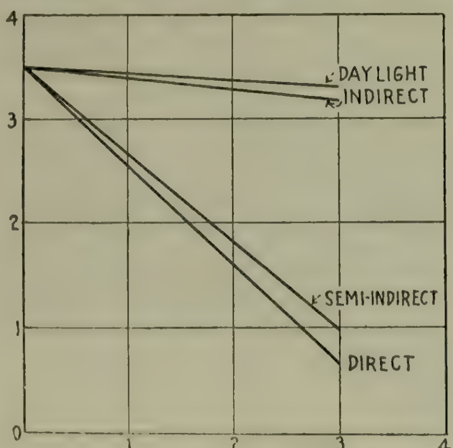
of moving pictures, even in the better moving picture houses, they are damaged little more by that in all probability than they are by

CHART VIII.

Distribution Series (Observer R)

Showing the loss of efficiency of the eye as the result of three hours of reading under the systems of direct, semi-indirect, and indirect lighting used, and daylight.

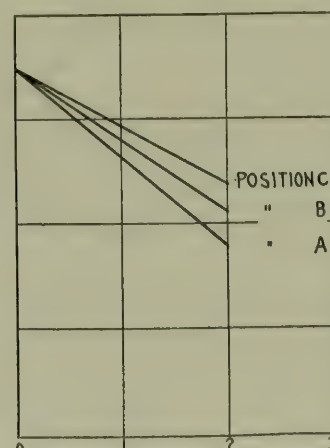
Lighting system	Watts	Foot-candles Horizontal	Vertical	45°
Daylight	—	5.5	1.32	4.2
Indirect	800	5.2	1.36	3.5
Semi-indirect .	760	5.8	1.45	4.0
Direct	880	4.2	1.41	2.6



Motion Picture Series (Observer R)

Showing the loss of efficiency of the eye caused by two hours observation of motion pictures.

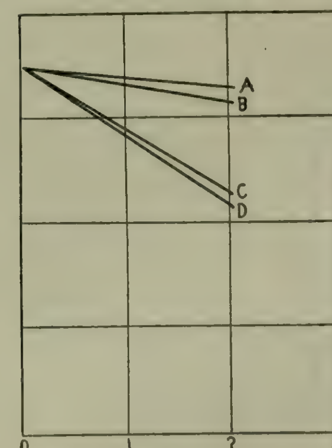
Position A, 25 ft. from projection screen
Position B, 48 ft. from projection screen
Position C, 71 ft. from projection screen



Distribution Series (Observer G)

Showing the loss of efficiency of the eye as the result of two hours reading under the systems of direct, semi-indirect, and indirect lighting used, and daylight.

	Lighting system	Watts	Volts	Foot-candles Hor.	Ver.	45°
A	Daylight	—	—	5.5	1.32	4.2
B	Indirect	800	107	5.2	1.36	3.5
C	Semi-indir't	760	107	5.8	1.45	4.0
D	Direct	880	107	4.2	1.41	2.6



reading steadily the same length of time under the greater part of the lighting that is now in actual use.

A graphic representation of the results of Table XXII is given in Chart VII. For the sake of comparing the effect of motion pictures on the eyes with the effect of reading steadily under the direct, semi-indirect, and indirect systems of lighting we have employed, Chart VIII has been prepared.

THE TENDENCY OF DIFFERENT LIGHTING CONDITIONS TO PRODUCE DISCOMFORT, AND A COMPARISON OF THE TENDENCY OF THESE CONDITIONS TO CAUSE LOSS OF EFFICIENCY AND TO PRODUCE DISCOMFORT.

In the former papers we have held that the general level or scale of efficiency of the fresh eye, loss of efficiency as the result of work, and the tendency to produce discomfort are all separate aspects of the problem of lighting in its relation to the eye, and that our knowledge of each must be obtained by different methods of investigation. A correlation between these three moments is doubtless possible, but that correlation should be founded upon the results of careful investigation; it should not be assumed. It is our purpose in this section of the paper to show the relative tendency of the different conditions of lighting we have used to produce discomfort, and to make a rough comparison of each condition to cause loss of efficiency and to produce discomfort. Any comparative study of the conditions producing discomfort necessitates a means of estimating discomfort. It is obvious that the core of the experience of discomfort is either a sensation or a complex of sensations. As such it should have a limen or threshold just as other sensations have; and just as we are able in general to estimate sensitivity in terms of the threshold value so should we in this case be able to use the threshold value in estimating the eye's sensitivity or liability to discomfort under a given lighting condition. Threshold values are usually determined by finding how much energy or intensity of a given stimulus, applied for a short interval of time, is required to arouse a just noticeable sensation. This form of procedure, however, is not adapted to the needs of our problem. It is much better to reverse the process and find how long the eye has to be exposed to a stimulus of a given intensity to arouse just noticeable discomfort. Our threshold thus

becomes a time threshold and is measured in units of time instead of units of intensity. In order to determine whether the judgment of the threshold of discomfort can be made with certainty and to perfect the method and to test in general its feasibility, an abstract investigation was undertaken first, running through an entire year, in which a better and more convenient control of conditions could be secured than is possible in the investigation of a concrete lighting situation. That is, we undertook to determine the comparative sensitivity of the eye to discomfort when a single source of light was exposed in different parts of the field of vision. In order to carry out this investigation a lamp house with a circular opening in one side 3 cm. in diameter was attached to the arm of a perimeter in such a way that the opening was always directed towards the observer's eye. In the lamp house could be placed a lamp of whatever candlepower was desired. The arm of the perimeter could be shifted to any meridian in which it was desired to work and the lamp house could be moved at will along this arm. It was thus possible to expose the light for any length of time in any part of the field of vision that was desired. Working in this way we have not only investigated the effect of many types of variation of the position of the light in the field of view, the effect of intensity of light, etc.; but we have studied and standardized the factors that influence the sensitivity and reproducibility of the judgment and have given our observers the training that was needed for the concrete investigation. In making the concrete investigation we have used every variation of the conditions of lighting described in this and the preceding paper. That is, the tendency to produce discomfort, measured in terms of the value of the time threshold, has been determined for all the conditions of lighting we have used in the tests for loss of efficiency. Two cases may be made of the investigation,—a determination of the tendency to cause discomfort when the eye is at rest, and a determination of this tendency when the eye is at work. Both of these cases were included in our investigation. The following determinations were made. (a) The time threshold of discomfort was gotten when the observer was sitting with the accommodation muscles relaxed and with the fixation muscles as nearly relaxed as was practica-

TABLE XXIII.—DISTRIBUTION SERIES.

Showing a comparison of the tendency of the direct, semi-indirect, and indirect installations of lighting used in the distribution series to cause loss of efficiency and to produce discomfort. The loss of efficiency is the result of three hours of work. The tendency to produce discomfort is estimated by the time required for just noticeable discomfort to be set up.

Position of observer	Lighting system	Watts	Foot-candles Horizontal	Foot-candles Vertical	45°	Per cent. loss of efficiency	Time limen of discomfort in seconds (not reading)	Time limen of discomfort in seconds (reading)
I.	Indirect	800	5.2	1.36	3.5	8.6	263	100
	Semi-indirect	760	5.8	1.45	4.0	72.0	15	8
	Direct	880	4.2	1.41	2.6	81.0	10	9
II.	Indirect	800	5.1	1.98	4.2	6.3	259	103
	Semi-indirect	760	6.1	2.5	4.7	37.0	26	14
	Direct	880	4.65	2.75	4.4	58.3	20	13
III.	Indirect	800	3.9	2.1	4.0	7.7	255	99
	Semi-indirect	760	5.0	2.6	5.4	22.0	120	35
	Direct	880	4.0	2.9	4.6	31.0	55	24
IV.	Indirect	800	2.9	2.1	3.6	6.6	265	101
	Semi-indirect	760	3.4	3.0	4.4	19.0	240	87
	Direct	880	3.0	3.4	4.5	23.0	235	57

TABLE XXIV.—INTENSITY SERIES.

Showing a comparison of the tendency of the direct, semi-indirect and indirect installations of lighting for the different intensities used in the intensity series to cause loss of efficiency and to produce discomfort. The loss of efficiency is the result of three hours of work. The tendency to produce discomfort is estimated by the time required for just noticeable discomfort to be set up.

Lighting system	Watts	Foot-candles Horizontal	Foot-candles Vertical	Foot-candles 45°	Per cent. loss in efficiency	Time limen of discomfort in seconds (not reading)	Time limen of discomfort in seconds (reading)
Indirect..........	800	5.2	1.36	3.5	8.6	263.0	100
	480	3.0	0.765	1.97	8.0	265.0	103
	320 (with socket extenders)	1.7	0.49	1.08	9.1	256.0	98
	200 (with socket extenders)	1.48	0.407	0.95	5.7	251.0	104
	320 (without socket extenders)	1.33	0.39	0.87	23.0	50.0	33
	200 (without socket extenders)	1.16	0.37	0.76	40.0	20.0	14
Semi-indirect.....	320	2.2	0.58	1.52	11.4	102.0	35
	200	1.6	0.45	1.15	40.9	62.0	16
	480	3.3	0.94	2.4	50.0	50.0	15
	760	5.8	1.45	4.0	72.0	15.0	8
	800	6.8	1.82	4.5	78.0	14.0	3
Direct (16 lamps).	240	1.23	0.54	0.935	57.4	23.5	17
	365	1.6	0.6	1.33	62.0	14.0	11
	400	1.86	0.8	1.46	65.0	12.0	11
	880	4.2	1.41	2.6	81.0	10.0	9
Direct (8 lamps)..	200	1.16	0.45	0.85	34.3	56.0	27
	120	0.64	0.32	0.49	45.5	52.0	15
	320	1.97	0.65	1.39	55.5	23.0	13
	480	2.6	1.02	2.00	67.0	20.0	12

ble under the conditions. That is, the observer sat in the positions shown in Fig. 1, p. 452a, and took an easy fixation of an area at the level of the eye on the opposite wall of the room. The fixation distance, for example, for Position I, Fig. 1, p. 452a, was 22 ft. Since blinking was found to be one of the variable factors which influ-

TABLE XXV.—EYE SHADE SERIES.

Showing a comparison of the tendency of the direct, semi-indirect, and indirect installations of lighting used in the distribution series to cause loss of efficiency and to produce discomfort when the eye was protected by an opaque eye shade with a dark lining and by an opaque eye shade with a white lining. The loss of efficiency is the result of three hours of work. The tendency to produce discomfort is estimated by the time required for just noticeable discomfort to be set up.

Lining of eye shade	Lighting system	Watts	Foot-candles Horizontal	Foot-candles Vertical	Foot-candles 45°	Per cent. loss of efficiency	Time limen of discomfort in seconds (not reading)	Time limen of discomfort in seconds (reading)
White	Indirect	800	5.2	1.36	3.5	9.1	85	50
	Semi-indirect .	760	5.8	1.45	4.0	10.6	81	48
	Direct	880	4.2	1 41	2.6	12.0	75	45
Dark	Indirect	800	5.2	1.36	3.5	33.0	23	19
	Semi-indirect .	760	5.8	1.45	4.0	33.4	19	15
	Direct	880	4.2	1.41	2.6	35.0	16	13

TABLE XXVI.—THE ANGLE AT WHICH THE LIGHT FALLS ON THE WORK.

Showing a comparison of the tendency to cause loss of efficiency and to produce discomfort of the angle at which the light falls on the work. The loss of efficiency is the result of three hours of work. The tendency to produce discomfort is estimated by the time required for just noticeable discomfort to be set up.

Kind of reflection from reading page	Foot-candles Horizontal	Foot-candles Vertical	Foot-candles 45°	Per cent. loss of efficiency	Time limen of discomfort in seconds (reading)
Diffuse	5.3	1.84	3.9	6.6	95
Specular....	5.3	1.84	3.9	14.3	30

ence the tendency to produce discomfort, the amount of blinking was made constant from test to test. This was accomplished by having the observer blink at equal intervals during the test, timing himself by means of the stroke of a metronome. The interval most natural and suitable for this purpose was determined for

each observer separately. In the results given in the following table a three-second interval was used. And (b) the time threshold of discomfort was determined when the observer was reading from print and paper similar to that used in the loss of efficiency tests. In these tests all the conditions were kept as nearly the same as they were in the work on loss of efficiency as was possible. The results of both of these sets of experiments on the tendency to produce discomfort are shown in Tables XXIII–XXVI. The tendency to produce discomfort should be estimated, roughly speaking, probably as inversely proportional to the time it was required for discomfort to be set up. The time required for discomfort to be set up is given in the tables. In order to make convenient a comparison of the tendency of the various conditions of lighting to cause loss of efficiency and to produce discomfort the percentage loss of efficiency caused by the given lighting conditions is given in a parallel column in each table. The percentage loss of efficiency was computed by dividing the loss in the ratio of time seen clear to time seen blurred sustained as a result of work by 3.5, the standard ratio to which all the ratios at the beginning of work were reduced. A rough correspondence of the tendency to produce discomfort and to cause loss of efficiency will be noted in every case. This correspondence by no means amounts to a 1 : 1 correlation, however. In Table XXIII is given the comparison of the tendency to cause loss of efficiency and to produce discomfort for the distribution series; in Table XXIV, for the intensity series; in Table XXV, for the eye shade series; and in Table XXVI, for the series showing the effect of the angle at which the light falls on the work.

In conclusion we wish to state that in this work, and the work reported in the former papers, the purpose has been primarily to procure methods of working and to find out, as broadly as one may, the applicability of these methods to the problems surrounding the hygiene of the eye. While in many places attention has been called to results that seemed to have general significance, the intention has been, in general, to limit all comments and conclusions strictly to the conditions under which the work was done.

SOME RECENT EXPERIMENTS ON VISION IN ANIMALS.*

BY H. M. JOHNSON.

Synopsis: The *Cebus capuchin* monkey has visual acuity of the same order as that of man. Under the same experimental conditions the monkey yielded a stimulus-threshold of 57 seconds of visual angle as compared with an average of 49 seconds with a mean variation of 3 per cent. for five trained photometrists. Two chicks under the same conditions gave stimulus-thresholds of over 4 minutes, while similar tests on two dogs yielded negative results. The monkey's difference-threshold for size of visible bands is as low as 3 per cent. under optimal conditions. One chick failed to acquire discrimination on the basis of difference in size; another individual yielded threshold values some ten times greater than those obtained for the monkey. The chick may be trained with difficulty to distinguish large differences in direction between two systems of striae whose members are respectively equal in width. The monkey, after similar training on other problems, acquired this form of discrimination and perfected it during the first day's training. Determinations were made by the discrimination method, the stimuli being two modified Ives-Cobb visual acuity test objects. The results are consistent with those obtained by other experimenters on color vision and discrimination on the basis of difference in size and form. Detailed reports of the author's experiments are to be found in the *Journal of Animal Behavior.*

Recent experimentation on vision in vertebrate animals has bearing on certain factors considered in theories of evolution. The Darwinian theory for example assumes that certain animals are capable of making differential responses to specific differences in visual objects. In the doctrine of sexual selection it is asserted that certain pattern-markings of hair or plumage are of value to the animal possessing them, in that they enable their possessor to secure a desirable mate. The doctrine of natural selection asserts that certain animals and birds are "protectively" colored or marked, the patterns in question being hard to distinguish from the animals' immediate environment. Conversely it is implied that if the coloring or marking were different the animals' natural enemies could find him more readily. Certain experimen-

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

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ters on vision in animals are interested in the question whether these theories attribute to certain animals better visual discriminative ability than these animals can be experimentally shown

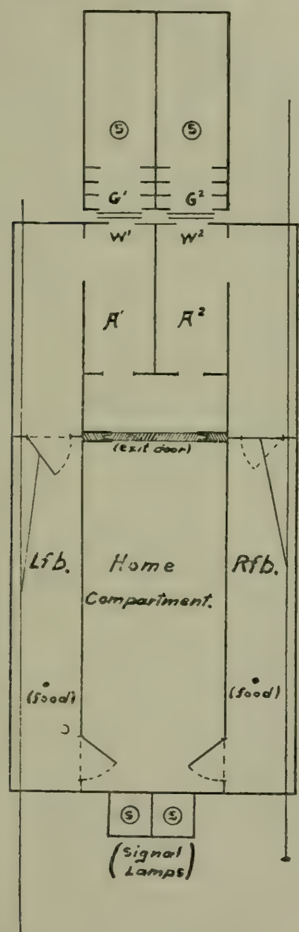

Fig. 1.

to possess. This is one of several questions of general interest which led to the present and other recent work.

The problems attacked require that the animal be placed in a situation in which he can be made to establish a discrimination-habit; that in forming and in maintaining this habit other sources

of help than visual stimuli be excluded; and that the visual stimuli be controllable so that only the stimulus-characteristic under study (*e. g.*, difference of wave-length, intensity, extent, form, disposition of brightnesses, etc.) shall be effective. The most successful method which has been utilized in this country is one which Professors Robert M. Yerkes and John B. Watson developed. The method is based on the fact that animals seek to obtain food and to avoid punishment. The animal under study is required to choose one feeding-place and to avoid another. The place to be chosen is indicated solely by one visual object (the "positive stimulus") and the place to be avoided is indicated by another visual object (the "negative stimulus"). The two objects which constitute the stimuli to be discriminated are interchangeable. The details may be readily seen in the accompanying diagram, Fig. 1. This represents in floor plan a box first used by Professor Yerkes, as modified for the author's present work. The animal is placed in a home-compartment H, from which he is released through the exit-door at the end. Food is already present in each of the food-compartments, Lfb and Rfb, which the animal may enter by passing through Alley A^1 or A^2, as the case may be. The test-objects, G^1, G^2, are presented to the animal at the windows W^1, W^2, at the end of the respective alleys A^1, A^2. A false floor is placed in each alley, hinged at the end next the window, and supported at the free end by a light spring. These floors are covered with brass strips which serve as electrodes, alternate members being connected with corresponding poles of the secondary coil of an inductorium. A double-throw switch determines which of these "punishment grills" shall receive the induced charge. The charge is always placed on the grill under the "negative" stimulus. When the animal steps into the alley he depresses the punishment grill, and in so doing closes the circuit through the primary coil and breaks the circuit through one of the signal lamps. In this way the choice is recorded automatically, and it is not necessary for the experimenter to watch the animal while the latter is in the act of choosing. The entrance door to the food-box to be chosen is not opened until the animal has entered the alley beneath the positive test-object. After the animal has obtained the food, and the experimenter has recorded

the choice and arranged the stimuli for the next trial, the animal is readmitted to the home compartment through a door opening directly into it from the food-box, the exit-door of the latter having been closed meantime. It should be remarked that certain experimenters do not feed the animals for correct choices, but punish them for incorrect choices. In such procedure the animal's incentive is to escape from the home-compartment and to avoid punishment. Other experimenters do not punish the animals for incorrect choices, but feed them for correct choices. In the present work the experimenter used both incentives combined. The stimuli are presented in a right-left order predetermined by the use of a well shuffled pack of cards. In 20 presentations the positive stimulus will appear ten times at W^1 and ten times at W^2, and the negative stimulus *vice versa*.

The first step in work of this kind is a course of training in which the difference between the stimuli is quite large. The animal often forms a "position-habit" early in the work—invariably choosing a certain food-box or choosing them in a perfectly regular order, regardless of the stimuli. These "position-habits" are often persistent. If the type of discrimination is not difficult, a bird or higher mammal can usually be trained to discriminate perfectly in three or four weeks of daily training. Ten to twenty trials or presentations are usually given in one daily "series." After the animal has learned to attend to the test-objects the number of trials may be increased—depending on the ease with which the animal becomes restless or fatigued and upon his capacity for food. The adult chick can be given from 50 to 60 trials in a single daily series if the amount of food given after each choice is small. After the animal has learned to discriminate, the difference between the stimuli is reduced by small steps until discrimination breaks down. This point is arbitrarily called the animal's threshold. Experience has demonstrated this method to be practicable and reliable if the stimuli are carefully controlled.

Some experimenters have used for stimuli spectral bands, diffused on plaster surfaces placed at the windows of the experiment-box. They have prepared their stimuli in such a way that the latter are accurately measurable and highly controllable as to

wave-length, intensity and saturation. They have obtained definite results, both positive and negative, on various animals as to the range of wave-lengths to which the latter are sensitive, as well as the degree of sensitiveness to difference of wave-length.

Other experimenters have used test-objects designed to test the animals' ability or inability to discriminate similar forms (*e. g.*, circles) of varying sizes, and equivalent areas of varying form. Some of these experimenters have also attached the question of brightness-sensitivity by the same general method. Some of these results will be mentioned presently.

The work of the author, which will be described in some detail, grew out of an interest in some earlier work by Casteel on the painted turtle. Casteel used the general method which has just been described, the stimuli being alternate "black and white" striae on cardboard fastened to the entrance to the food-boxes. In the first experiments the striae on the positive and those on the negative field were respectively equal in width but lay in different directions. The animal was trained to choose the vertical system and to reject the horizontal system. As Casteel was seeking to demonstrate only that the turtles were responding to the striation as such, he did not attempt to control the distance of test-objects from the animals' eyes at which choice had to be made. He obtained perfect discrimination with some animals when each member of the two systems of striae was only 2 mm. wide. He then presented the animals to another problem in which the striae in the two systems were respectively unequal in width, but lying in the same direction. He obtained perfect discrimination when the width-difference was very large, and highly accurate choices when the individual striae in one system were 3 mm. wide, and in the other system 2 mm. wide. He did not attempt to find the limits of the animals' stimulus-sensitivity or difference-sensitivity.

The writer has been working on a group of animals whose retinal developments varies widely: the dog and cat, the domestic chick, the Cebus monkey and the crow. The problem attacked is the difference in pattern-vision which exists among these animals under given conditions of illumination, the patterns used being alternate dark and bright bands equal in width. In some problems the variable factor is the band-width in the positive and negative

systems, respectively; in other problems the variable factor is the direction in which the two systems respectively lie. The first question to be settled is, how wide must the individual members of a system of striae be, for the striate field to be discriminable at a given distance from a plain field, equal to the former in form, area and mean brightness? For investigating this question the writer used as stimuli two Ives-Cobb visual acuity test-objects, indicated as G^1, G^2, in Fig. 1. A diffusing screen of opal glass was placed close behind each test-object. The latter were independently illuminated and equated in brightness at 12.2 candles per square meter. The sources used were 60-watt tungsten lamps, connected in multiple, operated at a specific consumption of 1.25 watts per candle, the source of current being a 25-ampere storage cell, and the current kept constant by the use of a voltmeter and a rheostat. The two fields thus prepared were both striate. The individual members of the negative system were about 0.1 mm. wide, and it was assumed that at the distance given they were too small to be resolved by the eye. The individual striae on the positive field were made 2.23 mm. wide at the beginning of the training, but this value was found too small for the dogs. The mounting of the test-gratings used by Cobb was modified so as to permit instantaneous change from a given band-width to another given width, the gratings being rotated over each other by a lever mechanism between limits determined by the setting of two stops controlled by a micrometer screw. Thus either test-object could be made at will to present a sensibly uniform field or a field of a given striation.

A set of movable stops was constructed to fit into the experiment-box in front of the entrance to alleys A^1, A^2. A different stop was used for each animal, so as to make it impossible for any of them to bring the eye nearer than 60 cm. to the test-object without stepping into the alley and registering a choice.

The results obtained on the first dog—a pure-bred male English bull-terrier—were negative, but not clearly so. He learned in 18 days to choose the alley under the positive test-object and maintained discrimination for several days during which the width of striae on the positive field was being reduced. The experimenter introduced a control test, however, which revealed

that the animal had been testing the two punishment grills for electrical charge, and maintaining discrimination on that basis. (Hitherto the circuit through the primary coil of the inductorium had been kept closed throughout the daily series of trials.) The dog's behavior—sniffing violently at the entrances of the two alleys—suggested that in this part of the work he may have been sniffing for ozone or for some gas similarly generated, about the charged electrodes. As soon as this source of help was removed the dog ceased to discriminate. Very doubtful evidence of discrimination was obtained when the band-width on the positive field was about 4 mm.—near the limit of the instrument—but this behavior was not persistent. A second dog—a pure-bred female beagle-hound—did not give evidence of discrimination in 900 trials.

The two chicks—Indian gamecocks—learned the problem readily. Chick 1 required very careful handling as he was easily disturbed by punishment. He ceased to discriminate when the band-width on the positive field was reduced to 0.71 mm., subtending a visual angle of 4′ 4″ at the distance given. Chick 2—a more satisfactory subject—ceased to discriminate when the band-width on the positive field was reduced to 0.74 mm.—subtending a visual angle of 4′ 14″ at the distance given.

Monkey 2—an adolescent Cebus *capuchin*—discriminated until the band-width on the positive field was reduced to 0.163 mm.—subtending a visual angle of 57″. For practical purposes these values may be taken as thresholds. Monkey 1, a cat and a crow died during the early stages of experimentation.

For purposes of comparison the author tested by the method of limits, the visual acuity of five members of the staff of the Nela Research Laboratory, using the same stimuli under the same visual conditions as obtained in the work on the animals. All the observers are skilled photometrists, four being physicists and one a physiologist. J, whose values are shown separately, is a high school student.

The results were as follows:

Observer	Mean threshold	M. V. per cent.
F	48″	3
Co	50″	3
L	54″	3
Ca	48″	2
W	46″	4
Average	49″	3
J	54″	4
Monkey 2	57″	Obtained by discrimination method
Chick I	244″	Obtained by discrimination method
Chick II	254″	Obtained by discrimination method

It should be stated explicitly that results obtained by the method of limits are not directly comparable with those obtained on a different subject by the discrimination method. The attitude of the observer is different in the two cases, and the problem is somewhat different. It is believed however that one is safe in taking these results as showing that the visual acuity of the monkey is *of the same order* as that of the human subject; that the visual acuity of the chick is only 20 per cent. to 25 per cent. that of the monkey and man; while the visual acuity of dog 1 (taking somewhat indefinite records as those of discrimination) is not over 4 per cent. that of the monkey and man. The author is hesitant regarding the assumption in the case of the dog; for neither of these animals gave clear evidence of possessing sensitivity to visual detail.

The second question taken up is, how great a difference in band-width in two systems of horizontal striae distinguishable by the animal as such, is necessary to enable the animal to discriminate them? This problem was attacked by the same general method as described above. The same test-objects were used as in the work on the first problem. For the chicks the brightness was the same as before—12 candles per square meter. The work on the monkey was done somewhat later, and at a lower brightness—6.67 candles per square meter. The animals used were the ones which had succeeded in learning the first problem—chicks 1 and 2 and monkey 2. Chick 1 failed to learn this problem. The following table shows the difference-threshold values obtained for chick 2 and monkey 2. The values taken for the chick are those at the first breakdown of discrimination. Those for the monkey are the values at which the average accuracy is

greater than 70 per cent. and less than 80 per cent. The results are therefore not closely comparable, but the uncertainty is no greater than other uncertainties inherent in the method. It is impossible to work the chick successfully when discrimination is difficult and the bird is receiving frequent punishment. This is not true in the case of the monkey, if conditions are carefully controlled.

The results are shown in the following table:

Width of striae on: Positive field	Width of striae on: Negative field	Difference in per cent. of standard stimulus
		CHICK 2.
*2.23 mm.	1.28 mm.	42
1.30 "	*0.91 "	33
*2.60 "	1.73 "	33
*3.12 "	1.80 "	42
1.56 "	*1.04 "	33
1.04 "	*0.74 "	40
		MONKEY 2.
1.772 mm.	*1.561 mm.	14
*1.561 "	1.301 "	17
0.887 "	*0.780 "	14
*0.780 "	0.673 "	14
0.610 "	*0.520 "	17
*0.520 "	0.479 "	8 (See remarks below)
0.413 "	*0.390 "	6
*0.390 "	0.371 "	5
0.321 "	*0.312 "	2.9
*0.312 "	0.304 "	2.6
0.232 "	*0.223 "	4
*0.223 "	0.210 "	6
*0.191 "	0.173 "	9
0.750 "	*0.780 "	3.8
*0.780 "	0.764 "	2+ (Greater than 2 and less than 3)

* Standard stimulus.

The results appear in the table in the chronological order of the tests. The results for monkey 2 show a progressive diminution from the first step (value of standard stimulus 1.561 mm.) to the fourth (standard = 0.312 mm.). It appeared necessary, therefore, to determine by a control test whether this was not due largely to effect of training. This test

was made at standard stimulus = 0.780 mm., and it showed that an important practise effect was present. The daily record sheets suggest that during the work at the third step (standard = 0.520 mm.) the animal acquired a higher standard of "attention" or a new criterion, which he maintained fairly well thereafter. Taking the later value as approximating the true threshold, according to this mode of reaction, for that region, the monkey's values in the different regions are quite close to those obtained in rough tests on two human observers. Their optimal results were at stimulus-values near his, and the threshold-values where the standard stimulus was smaller than 0.3 mm. tended to increase as did the monkey's. These results are not to be taken as final, however, as more detailed and more careful work may change them considerably.

A third problem is that of the least difference in direction occupied by two systems of striae whose members are respectively equal in width, which is necessary to effect discrimination. This problem also was attacked by the same method and with the same apparatus as the two preceding problems. The animals used were chicks 1 and 2 and monkey 2. Chick 1 failed to learn the problem, although he acquired perfect discrimination when a large difference in band-width was presented together with a difference in direction of 90°. Discrimination failed when the difference in band-width was reduced. Chick 2 learned the problem in 400 trials—with much greater difficulty than in the problem of striate-plain discrimination. Monkey 2 learned the problem during the first daily series, giving 90 per cent. accuracy for the twenty trials, and 100 per cent. accuracy in the series given the following day. His threshold and that of chick 2 have not been finally determined at this writing. Dog 1 has also been introduced to the problem, in order to ascertain if this problem is easier for him than the first one, in which he probably failed.

To sum up: the monkey possesses sensitivity to visual detail rivaling that of the best human subjects. His visual acuity is four to five times as good as that shown by the chicks, and his difference-sensitivity for size is proportionately much greater. The factor of direction of striation is much more effective for him than for the chicks.

A complete and satisfactory explanation of these results is not possible at present. The tests were made in dark surroundings but not with good darkness-adaptation. It is possible that the visual conditions were more favorable for the monkey than for the chicks and dogs: or the converse may be true. Since the original presentation of this report my colleague, Dr. P. W. Cobb, has tested the eyes of the animals used for refractive errors. His report will be published shortly. It is sufficient to say here that dog 1 and chick 2 were found practically free from refractive error, hence the disparity between their results and those of monkey 2 is not explanable on that basis. The different degrees of retinal development seem by far the most important factor at present. The dog has no fovea and the existence of a "sensitive area" in the paracentral region is doubtful. According to Slonaker the chick is the only bird with the exception of the guinea fowl which has not a well defined fovea. The monkey has a retina almost like that of man. The crow possesses a well developed fovea, *nasal* to the nerve-entrance. Many birds, especially birds of prey, have two foveas, one nasal the other temporal to the entrance of the optic nerve. The nasal fovea is used in monocular vision, the temporal fovea in binocular vision. If the crow had yielded results closely comparable with those obtained on the monkey, and the cat yielded results like those obtained on the dogs, the author should have been tempted to refer the differences in results to the differences in retinal structure. Such interpretation might have to be modified after future tests on optimal conditions of discrimination for the various animals.

It may be interesting to recall some results which other experimenters have obtained in work on other problems of vision with the same species.

The dog has been tested for color-vision by numerous experimenters, but by none so far whose stimuli were adequately controlled. There is no evidence whatever that he is sensitive to differences of wave-length. There is good evidence that rodents, whose retinal development is very like that of the dog, are color-blind and have a shortened spectrum. Watson has investigated the range of effective wave-lengths for the chick, and reports that it extends from $\lambda = 400\,\mu\mu$ to $\lambda = 715\,\mu\mu$, the maximum

lying near $\lambda = 500\ \mu\mu$, and the luminosity-curve being roughly similar to that for the experimenter's eye under the same conditions. Lashley and Watson have demonstrated the Purkinje phenomenon in the chick, and have also obtained discrimination between monochromatic bands, apparently based on wave-length difference alone.

There is incomplete evidence that the Rhesus monkey discriminates between monochromatic bands on the basis of wave-length and that the wave-lengths in the region of red have a low stimulating value. No reliable work on color-vision in the cat and the crow has been published.

The dog has shown no evidence of ability to discriminate between visual objects differing only in form. The writer once worked on a single dog, using a circle and its equivalent square as stimuli. Discrimination was established in about 1,000 trials when the brightness of the positive stimulus was 4 times that of the negative stimulus. Discrimination failed when the stimuli were equated in brightness, and it was not re-established in 600 trials. Breed and Bingham have shown certain individual chicks to be sensitive to differences of about 40 per cent. in luminous intensity and area. They also trained several chicks to discriminate between visual objects differing only in form—circles from equivalent triangles and squares. Watson also obtained positive results with the Rhesus monkey, but has not yet published them. Coburn, in some rather rough preliminary tests, obtained results on the crow which compare very favorably with those obtained by Breed and Bingham on the chick.

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TRANSACTIONS

OF THE

Illuminating Engineering Society

VOL. X — OCTOBER 10, 1915 — NO. 7

REPORT OF THE COMMITTEE ON PROGRESS.*

Where is the way where light dwelleth? and as for darkness, where is the place thereof? Job 38: 19.

To the Illuminating Engineering Society:

During the past year there have occurred two events of striking significance, which may be symbolized by two flaming torches, one signalizing destruction and conflagration, the other spreading its glow over construction, progress and enlightenment. One heralds animosity and antagonism; the other discloses amity and friendly relationship. The one is the sign of war; the other a proof of peace. In spite of the one progress has continued; in conjunction with the other the art of illumination has been extended. The European war, repellent in its awful carnage, has afforded grim and hitherto undreamt of possibilities in the use of light. The Panama-Pacific Exposition welcomes the whole world and stands as a magnificent example of the art of applied illumination.

Illuminating engineering is becoming recognized as a profession as attested by the employment of an illuminating engineer to take care of the lighting of the Exposition and by the announcement by the United States Government of examinations for the position of illuminating engineer in the office of the supervising architect at Washington.

The enormous demand for all sorts of material required by the nations at war has necessitated night work in a large number of foreign factories. This has stimulated interest abroad in satisfactory and efficient systems of interior illumination.

It will be noted that the list of subjects covered by this year's

* A report presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

report is slightly different from that shown in the report of last year. Some subjects are missing, others have been added. This is natural, since progress is continually appearing in new directions.

The committee again desire to express their thanks for the help accorded by the engineers in charge of lighting in various cities and to the representatives of those manufacturers who have furnished information and data.

Respectfully submitted,

F. E. Cady, *Chairman,*
P. W. Cobb,
T. J. Litle, Jr.,
L. B. Marks,
T. W. Rolph.

SUBJECTS.

GAS AND OIL LAMPS AND APPURTENANCES.

Burners.—A very important development in incandescent gas lighting is the recent introduction of an upright unit fitted with three miniature mantles in soft form and made from artificial cellulose fiber. This type of lamp operates well over a reasonably fair range of gas pressure and qualities, is efficient and requires no enclosing draught-inducing cylinders. It can replace open-flame burners without glassware change on present fixtures and furnishes a means of obtaining semi-indirect or indirect illumination.

Several new types of inverted burners provided with inclined chute-like heat baffles to divert the products of combustion entirely away from the fixtures have been worked out in sizes giving approximately 100, 150 and 250 horizontal candlepower. These units are furnished with non-tarnishable, heat-resisting lacquer and are so constructed that the heat discharge vents are completely hidden. Being entirely of metal they can be finished to match the fixture on which they are to be used. The gas lamp designed to take advantage of the fact that the hottest part of the flame from a meeker or inverted Bunsen burner is in the neighborhood of the small green inner cones and as mentioned in last year's report has been in use in Germany[1] and proved the prediction of unusual sturdiness and long life.

An elaborate study of the room ventilating action of various types of gas burners has been made in England.[2] The results show that the ventilating efficiency is greatest for upright burners; that of the inverted burners, those giving a clear passage for the gases had the greatest ventilating efficiency; that the addition of deflectors intended to protect the fittings from the action of the gases reduced the ventilating efficiency by as much as 9 per cent. Experiments made in this country, however, show that when the stack is properly designed, higher efficiencies are obtained with deflectors due to a superheating of the mixture before burning. Globes with a very open base had no effect on the ventilating efficiency, but those with a constricted opening produced a reduction dependent on the area of that opening.

[1] *Jour. f. Gas.*, July 25, 1914, p. 741.
[2] *Jour. of Gas Light.*, June 8, 1915, p. 573.

To produce the best results with the use of gas for lighting purposes, the character of the Bunsen flame used in conjunction with gas mantles must not change materially. In order to enable a manufacturer to ascertain how closely his service is maintaining constancy of burner conditions, a gauge has been developed.[3] It consists of a small, slender upright Bunsen tube of exact design and carefully drilled orifice, mounted on the same base with a pressure gauge. A scale is placed at the side of the Bunsen tube in order to check the length of the inner cone. Any variation of the cone length above or below a specified point can be easily noted. The gauge is not calibrated to indicate any specific quality of gas, but will show only those changes which will effect Bunsen burner service.

Despite the long life and high efficiency of the present day gas mantle efforts are still being made[4] by inventors to either strengthen the structure or intensify the illuminating power by the application of some solution after the mantle has been purchased. Such efforts have not in the past been very successful.

Whether illuminating gas causes the fading of colors in fabrics has been made the subject of careful testing,[5] experiments having been continued for a period of ninety days. It was found that the deterioration of color either due to temperature, illumination, or the products of combustion arising from the use of gas lighting is of no practical importance compared with the effect of daylight.

Automatic Lighters.—The protected pilot tip so successfully applied to outdoor gas arc lamps has now been modified for use on indoor burners reducing the pilot flame outages to a minimum. A very simple electric gas cock for the distance control of gas burners has been produced. In Florence, Italy, a system of distance control for gas lighting[6] has been in satisfactory use for the past three years. As a result of a recent successful test by military authorities, in which the city gas was shut off at a specified time and relighted after a predetermined period, it is expected that this system will shortly be employed in Italian frontier and

[3] *Light. Jour.* (U. S.), Dec., 1914, p. 82.
[4] *Jour. of Gas Light.*, Feb. 23, 1915, p. 442.
[5] *Ill. Eng.* (Lond.), June, 1915, p. 292.
[6] *Jour. of Gas Light.*, Mar. 2, 1915, p. 504.

coast towns. In general[7] inventors are looking toward means for making distance lighting by pressure waves selective.

Artificial daylight units using gas as the illuminant[8] have been developed and also units especially designed for photographic work which will be mentioned later.

Heating Value.—The use of the calorific standard for gas in place of the candlepower standard is increasing in this country.[9] In many localities both standards are still required, but it seems to be a quite general experience that if the gas is maintained at the right calorific value, the candlepower value will be satisfactory. At the 1914 convention of the American Gas Institute there was referred to the Board of Directors the question of adopting the Metropolitan No. 2 (Carpenter Argand) burner as the standard burner in the determination of gas candlepower. It has been suggested[10] by the Bureau of Standards that "for those places where a candlepower specification is necessary in order to afford protection to users of open-flame lights, . . . an open-flame burner should be used in testing the gas candlepower." As the number of open-flame burners used in this country is relatively small the advisability of adopting this suggestion has been seriously questioned. The Bureau also suggests that the adoption of any standard burner might delay the present tendency toward the adoption of heating value standards.

Data have been given[11] of experiments which indicate that calorific value, specific gravity, and gas candlepower do not definitely specify a gas for commercial purposes. Gases which are identical in these properties may yet differ so in composition that the resultant flame temperatures will differ greatly and hence the performance of incandescent lighting appliances cannot be predetermined on this basis. It has been found, however, that heating values above 600 B. t. u. are not desirable for incandescent gas lighting.

A method has been devised[12] to enable a gas company to determine the candlepower of coal gas produced at night as well as

[7] *Jour. of Gas Light.*, May 18, 1915, p. 409.

[8] *Light. Jour.* (U. S.), Dec., 1915, p. 281. *Proc. Amer. Gas Inst.*, vol. IX, p. 886, 1914.

[9] *Proc. Amer. Gas Inst.*, vol. IX, 1914, p. 367.

[10] *Gas Inst. News*, March, 1915, p. 51.

[11] *Amer. Gas Light Jour.*, July 5, 1915, p. 1.

[12] *Amer. Gas. Lt. Jour.*, Apr. 5, 1915, p. 219.

by day. A holder, 3 ft. (0.90 m.) in diameter and 3 ft. high is used and the flow of gas into it is regulated so that it will just fill up during the night or during the day. Tests made on the candlepower of the gas collected in the holder agreed exactly with those made according to the "periodic method" in which readings are taken periodically when the candlepower is at a maximum, at a minimum, and at the average.

Oil Lamps.—Of late years[13] the use of high pressure oil lamps with incandescent mantles has considerably extended the employment of this illuminant. A Swedish type using Russian paraffine oil, consists of two essential parts, the lamp itself and the container for the oil. The latter is separated into two compartments, one containing the air compressed to 6 atmospheres by means of a small hand pump, the other holding about 2 gallons of oil. The pressure used in the container is maintained constant at 2½ atmospheres by means of a reducing valve. The lamp is started by means of a little methylated spirit. A kerosene oil mantle lamp is now being used in this country which on recent tests showed a candlepower roughly twice, with a consumption of only half as much oil as any one of several circular-wick center draft luminous flame lamps of the ordinary type.

ELECTRIC INCANDESCENT LAMPS.

Gas-filled Tungsten Lamps.—While the development of the tungsten filament electric incandescent lamp has been fairly rapid as compared with that of the carbon filament type, it would seem as if the progress each year was greater than that of the previous year and that salesmen would hardly have time to dispose of one product before an improved successor was available.

In last year's report[14] reference was made to the sizes of non-vacuum gas-filled tungsten lamps then available, 400 being the lowest wattage for multiple burning. Now 100, 200 and 300-watt sizes are made.[15] In May all sizes from 200 to 1,000 watts for circuits of 220 to 250 volts were [16] put on the market. In England[17] 60-watt lamps of this type were announced July 1. In the 60-watt and 100-watt lamps argon gas is used instead of

[13] *Ill. Eng.* (Lond), Jan., 1915, p. 37.
[14] TRANS. I. E. S., 9, 1914, p. 522.
[15] Report of Lamp Committee *Nat. Elec. Light Assn.*, June, 1915.
[16] *Elec. Jour.*, June, 1915, p. 252.
[17] *Elec. Times*, July 1, 1915, p. 1.

nitrogen. In Germany[18] for 100 to 130-volt circuits, 40 and 60-watt sizes, and for 200 to 250-volt circuits, 75 and 100-watt sizes were advertised at about the same time.

It should be recalled, however, that, while in lamps with filaments of large cross section, and, for multiple burning in general of high wattage, the advantage gained in being able to run the filaments at high temperatures and hence high lumens per watt is great compared with the loss in wattage due to convection and conduction in the gas, this advantage is greatly decreased, in the case of filaments of small cross-section such as those used for low wattages on multiple circuits, and hence the comparatively slow introduction of the latter.

There has been a marked improvement in the various mechanical features of the gas-filled tungsten lamp. Early lamps gave trouble due to the loosening of the bases because of the effect of the heat on the base cement. This has been remedied. A new solder has been devised to overcome the former melting of the solder at the junction of the leading-in wires and the base. Rusting or scaling of the leading-in wires has been eliminated by the use of a special coating. The distance between the filament and the stem seal has been increased, thus decreasing the temperature of the seal.

Another important step in advance lies in the standardizing of the bulb,[19] which now incorporates the good features of the round and straight-side types, previously used, together with the long neck containing a mica disk to keep the seal and base portion of the lamp cool. The distance from the light center to the base has been made the same for the 300 to 500-watt sizes so that one type of fixture will do for any of these sizes. The use of the gas-filled lamp in special colored bulbs for use in photography will be mentioned under another caption.

Before the advent of the gas-filled tungsten lamp the use in Germany of street lamps of the series type was limited. But[20] the great advantage of the series gas-filled unit was evident, and

[18] *Elek. Zeit.*, June 24, 1915, p. 319.

[19] *N. E. L. A. Bul.*, Apr., 1915, p 246.

[20] *Zeit. f. Bel.*, Jan., 1915, p. 4.

hence an effort has been made to overcome the features formerly considered objectionable. A carborundum device has been used to some extent as a shunting arrangement for burned-out lamps.

Physics.—There has been a continuation of the study of the physical properties of the gas-filled tungsten lamp. Thus it has been found that[21] the spectral energy curves of a vacuum lamp at 1.2 watts per candle and a spiralled-filament gas-filled lamp operated at a color match with it, superpose very closely throughout the infra-red spectrum. Tests have been made to determine the effect of winding the filament in the gas-filled lamp in the form of a spiral and the results indicated no marked difference in the quality of the light emanating from the straight and spiralled filaments of tungsten in an atmosphere of nitrogen. When the luminous efficiency (ratio of the "visible" to the total amount of radiation emitted) of these two types (straight and spiral-wound filaments in a nitrogen atmosphere) was practically the same, the candles-per-watt output was found to be 15 to 20 per cent. higher in the spiralled filament, owing to the lessening of convection losses. When the straight filament was operating at about 0.5 watt per candle and the spiralled filament was operated so that the outside surface of a turn was set to the same emissivity as that of the straight filament, the spectral energy curves of the two showed that the spiralled filament emitted about 7 per cent. more infra-red energy than the straight filament. Hence the luminous efficiency of the latter under the given conditions was 7 per cent. higher than the former.

Experiments have also been made[22] showing that the so-called "stationary" film of gas about the filament of a gas-filled lamp as a matter of fact does not cling to the filament, but moves upward along it.

Vacuum Tungsten Lamps.—Since last year's report there has been an increase in the efficiency of the vacuum tungsten lamp of from 7 to 10 per cent. in sizes below 150 watts. In July a sign lamp for multiple circuits, 105 to 125 volts, was announced

[21] *Elec. World,* Nov. 28, 1914, p. 1048.

[22] *Elec. World,* Dec. 5, 1914, p. 1111.

using 7.5 watts and giving 5 candlepower. This is the smallest wattage, standard lighting-circuit lamp yet manufactured. The practise of introducing chemicals to delay the discoloration of the bulb has been extended to include the 10, 15, and 20-watt sizes and has permitted the operation of all vacuum lamps at higher efficiencies. The spiral winding in a concentrated form is now used in the 25, 40, and 60-watt sizes,[23] in addition to those sizes in which it was previously used. These lamps use the same size bulbs and have the same average mean spherical efficiencies as the regular type of the same wattage, but have a somewhat shorter life. In Germany small lamps for signal purposes have been developed[24] which are designed to be burned in series with apparatus or circuits whose active or inactive operation it is desired to verify. These lamps are obtainable for a range of current consumption from 0.4 to 12 amperes.

A method has been recently patented, in which[25] the wires sealed into the glass stem of electric lamps are coated with a chemical salt, thereby making a better seal. The patent also covers the use of metal plated wire for use in such seals.

In line with the continued efforts towards standardization there has been considered a plan[26] for settling upon two or three standard lamp voltages to be adopted as a basis for the manufacturer's output. This will simplify specifications.

The completeness with which the gas-filled street series lamps have superseded the vacuum type has resulted in the withdrawal of the street series vacuum lamps from the listed lamp schedules.

The tantalum lamp has now disappeared from the market and is being[27] rapidly followed by the carbon lamp. The demand for gem lamps has fallen off to such an extent that it is difficult to retain the present limits of candlepower and wattage. In the case of miniature lamps, the tungsten filament has so completely

[23] *Light. Jour.*, Mar., 1915, p. 65.

[24] *Elek. Zeit.*, Jan. 21, 1915, p. 27.

[25] *Elec. World*, Apr. 24, 1915, p. 1043.

[26] *N. E. L. A. Bul.*, Mar., 1915, p. 169.

[27] Lamp Com. Report. *Loc. Cit.*

replaced carbon that sales of tungsten comprise over 85 per cent. of the total of miniature lamps sold.

Rating.—It has become the almost universal custom to rate metal filament lamps in this country according to their watts input and apparently this method of rating has served to raise the prevailing standard of illumination. In England, however, a discussion before the British Illuminating Engineering Society[28] revealed the fact that this method of rating is by no means generally accepted as satisfactory. The preponderance of opinion seemed to be in favor of a return to some form of candlepower rating with a difference of opinion as to whether the unit should be the mean spherical candle or the lumen. In Germany also the subject has been considered at[29] a series of conferences held by the German Lamp Manufacturers who proposed the continuance of the voltage-wattage rating. The lighting committee of the German Association of Electrical Engineers discussed this proposal, but could come to no full agreement on the subject. A[30] representative from the Associations of Central Stations urged that it should be required by law to state the voltage, the upper and lower hemispherical candlepower, the total watts consumed and the watts-per-candle.

At the request of the[31] Society of Motor Manufacturers and Traders the British Engineering Standards Committee has been investigating standard tungsten filament lamps of the vacuum type for automobiles. The question of whether such lamps should be rated at all in candlepower is receiving the attention of the committee and in the meantime they are rated in actual watts or nominal candlepower. Standard bulbs and standard voltages are defined. For headlights a standard distance of 30 mm. from the contact plates to the center of the filament is prescribed.

In Germany the gas-filled lamps were formerly widely advertised as "half-watt" lamps. Recently[32] the largest manufacturers have made a determined effort to get away from this term, realizing that it is as misleading, and hence a cause of trouble, as the old designation of "2,000 candlepower" was in the case of arc lamps.

[28] *Ill. Eng.* (Lond.), Apr., 1915, p. 167.
[29] *Elek. Zeit.,* May 13, 1915, p. 236.
[30] *Elek. Zeit.,* May 20, 1915, p. 248.
[31] *Elec. Eng.* (Lond.), Feb. 18,1915, p. 69.
[32] *Zeit. f. Bel.,* Jan., 1915, p. 11.

Physics.—The disappearance of almost any kind of a gas introduced at low pressure into a bulb containing an incandescent tungsten filament has been investigated and it[33] has been found that there are four classes of reaction involved. The filament is directly affected by the gas; or the gas reacts with the vapor given off by the filament; or the filament acts catalytically on the gas, producing a chemical change in the gas, but no permanent change in the filament; or the gas is chemically changed or made to react with the filament by means of electric discharges through the gas.

Studies have been made also on the[34] temperature distribution in the neighborhood of a cooling junction of an electric incandescent lamp filament, and of the thermal conductivities of tungsten, tantalum, and carbon at incandescent temperatures.

ARC LAMPS.

A flaming arc lamp has been developed[35] in which the positive electrode is covered by an outside cylindrical layer of illuminating salts, which protect the inner electrode core against the oxygen of the air so that consumption is reduced. The electrode is of homogeneous carbon and the layer used is a mixture of calcium fluoride, sodium tungstate and potassium chromate. The negative electrode is an ordinary homogeneous carbon with a central core. The electrodes must be used vertically and are said to have a life of from 40 to 50 hours. The specific consumption including the series resistance for direct current is given as 0.14 watt per candle.

In the report of the Committee on Progress for 1913, reference was made[36] to some work on the relation of pressure and temperature in arc lamps. This work has been continued[37] and some striking results have been obtained. From these results the true temperature of the evaporating solid crater of the positive carbon at atmospheric pressure was deduced as 4,200° centigrade absolute, a value higher by 200° or 300° than that generally accepted heretofore. The temperature of the negative crater was found to be lower by several hundred degrees. If the pressure

[33] *Elec. World,* May 15, 1915, p. 1245.
[34] *Phys. Rev.,* vol. 4, 1914, pp. 524 and 535.
[35] *Elek. Zeit.,* Nov. 26, 1914, p. 1079.
[36] TRANS. I. E. S., Oct., 1913, p. 328.
[37] *Zeit. f. Beleu.,* Jan., 1915.

is decreased below one atmosphere the temperature of the positive crater decreases. When the atmospheric pressure is increased the temperature of the positive crater increases with a corresponding greatly increased efficiency. At a pressure of 22 atmospheres the surface brilliancy had increased to 18 times the value at one atmosphere pressure. These results were obtained with impregnated carbons, it having been found impossible to maintain a "true arc" with pure carbons at pressures greater than one atmosphere. Further experiments are to be made in connection with the action of the impregnating salts, the dimensions of the carbons, etc.

In a study[38] of metallic arc lamps comparative tests made on ferro-ilmenite and magnetite cathodes using solid copper anodes indicate the superiority of the former. A definite dependence was found between the temperature of the arc and its most efficient length, shorter arcs being more economical at low amperages and *vice versa*. Chromium compounds exercise a cooling effect similar to that of an excessively long arc. The efficiency of the arc was increased by amounts varying from 190 to 133 per cent. by the use of a ferro-ilmenite anode. Indications were that this was due to the heat resistivity of the material, other anodes of materials with approximately the same heat resistivity such as cold rolled steel, vanadium steel and graphite giving similar favorable results.

On alternating current circuits, arcs between carbon electrodes and those between metal electrodes act quite differently owing to the low heat conductivity of carbon. The relighting potential of carbon electrodes on an alternating current circuit of 50 cycles and 3 amperes does not exceed 100 volts, but the relighting potential of metal electrodes under identical conditions is almost equal to a static discharge potential. Experiments have been made[39] using an auxiliary arc to counteract the tendency of the metal arc to cool down. Combinations were tried of carbon and ferro-ilmenite electrodes. The results indicated the possibility of using a modification of Duddell's musical-arc circuit for the purpose of sustaining the alternating ferro-ilmenite arc during the zero point in the current curve by supplying the necessary

[38] *Elec. Rev. and W. E.*, Apr. 10, 1915, p. 691.
[39] *Elec. Rev. and W. E.*, May 8, 1915, p. 871.

relighting potentials from the circuit itself. It is hoped that a commercial alternating current metal arc may be thus developed.

An arc[40] lamp of an entirely new type is foreshadowed in a patent issued in England for an arc between tungsten or similar electrodes enclosed in a bulb containing nitrogen or other inert gas. The electrodes are horizontal and of small diameter, and the arc is struck by a simple thermo-mechanical device.

Some recent experiments on the temperature of the mercury arc as used in work on fluorescence have given results indicating values as high as 1,400° centigrade. Measurements were made on the discharge in a tube that had a platinum-iridium thermocouple sealed into it with one junction situated at the axis of the tube. The temperature of 1,400° C. was deduced by extrapolating about 200° beyond the calibration curve of the thermocouple. The investigation suggested that in all probability the temperatures indicated by a thermo-couple when exposed directly to the discharge are still very much below that corresponding to the mean molecular kinetic energy of the luminous vapor.

LAMPS FOR PROJECTION PURPOSES.

Searchlights.—Recently the[41] United States Navy has secured a searchlight of novel form, which has already found application in Europe. This instrument is 44 inches in diameter and has instead of the usual silver mirror, a gold mirror which can be controlled automatically from a distant station. It is claimed that the use of gold gives a beam of light which is more effective in showing detail and has greater penetrating power in case of fog than that coming from a silvered mirror.

In the Swedish army an oxy-acetylene searchlight is being adopted.[42] This apparatus employs a pellet of ceria on which the oxy-acetylene flame is concentrated. The consumption is stated to be about 40 liters of acetylene and 40 liters of oxygen per hour and enough of both is carried with the instrument to provide for 20 hours burning.

A portable searchlight[43] has been developed in this country in which a 20 in. waterproof projector is used with a 750-watt

[40] *Elec. Eng.* (Lond.), May 27, 1915, p. 229.
[41] *Sci. Amer.*, Apr. 24, 1915, p. 382.
[42] *Ill. Eng.* (Lond.), Feb., 1915, p. 84.
[43] *Elec. Rlwy. Jour.*, Mar. 27, 1915, p. 639.

focusing type non-vacuum tungsten lamp. The projector and battery weigh 600 pounds and are mounted on a two wheeled carriage. One charge of the battery is designed to give 7 hours continuous service.

Miner's Lamps.—As a result of the stringent rules of the British Home Office there has been a steady development in lamps for use by miners. Six new types have been approved.[44]

The Bureau of Mines has recently revised its specifications for miner's lamps under the caption "Schedule 6-A." The principal changes are in the candlepower rating and in the uniformity test.

Headlights.—A big reduction in power consumption without reduction in illuminating effect[45] in street and surburban railway headlights has been made possible by the new concentrated filament tungsten lamps which are replacing arc lamps for this work.

The importance of the problem of the glaring auto headlights which has caused so much adverse legislation and ill-feeling has been recognized[46] by the Society of Automobile Engineers as demanding immediate attention. A series of tests have been worked out which may be used as a standard definition of what constitutes a dangerous "glare" and the results of such tests will be submitted to manufacturers of headlights with a view to eliminating the trouble at the source. Future headlights are to be constructed according to scientific formulae removing the glare but thoroughly retaining the far-reaching effect of a searchlight upon the road itself.

A new method[47] of reducing the glare from auto headlights consists in the use of small curtains mounted on shade rollers contained in cylinders which may be attached above the lamps. The shades are raised or lowered by means of cords connected to a device operated from the driver's seat. When down they still transmit sufficient light for city driving. Another arrangement[48] consists in the mounting of two filaments in one bulb, one of 4 candlepower for city use, and one of 20 candlepower for country use. Fittings are now made[49] which enable a light to be

[44] *Elec. Eng.* (Lond.), May 6, 1915, p. 197.
[45] *Elec. Rlwy. Jour.*, Mar. 27, 1915, p. 639.
[46] *Sci. Amer.*, July 17, 1915, p. 59.
[47] *Pop. Mech.*, Mar., 1915, p. 397.
[48] *Elec. Rec.*, Apr., 1915, p. 38.
[49] *Elec. Rec.*, Feb. 5, 1915, p. 26.

mounted almost anywhere on an automobile, even on the windshield or fenders.

Signal Lights.—Fulfilling the forecast made in last year's report[50] semaphores are eliminated in a block signal system now being installed on one of the large railroad systems.[51] White electric lights are arranged on a black background so that the three positions of a semaphore can be imitated. Two boards corresponding to two semaphore arms are used for each track, the upper corresponding to the stop signal, the lower to the cautionary signal. These signals are used both by day and night.

The familiar oil lantern carried by train men is being displaced by an electric lantern[52] built along exactly the same lines, a dry battery being carried in the space formerly occupied by the oil, and a miniature tungsten lamp furnishing the light. Another portable lantern for railroad men consists of a nickel plated casing,[53] the top of which carries the battery, the bottom being flared so as to act as a projector and containing an incandescent lamp. The lamp is turned on or off by the bail which is made to snap into the vertical position when being used.

Owing to reckless automobile driving the old "Stop, look and listen" signs at grade crossings are no longer as efficient as formerly in preventing accidents. In consequence one railroad has inaugurated the use[54] of large illuminated billboards to educate the public in "Safety First" and warn automobilists and others to use care in crossing tracks. A new type[55] of railroad track warning signal consists of a blackened tube containing a condensing lens behind which is a strong incandescent lamp backed up by a reflector. The tube is mounted so as to point in the direction from which the motorist will approach and the placing of the light well back in the tube makes it almost as effective by day as by night.

Street traffic controlled by means of signal lights described in last year's report is being tried out[56] in Pittsburgh.

There is evidence of the increased use of light as a danger

[50] Trans. I. E. S., IX, No. 6, 1914, p. 530.
[51] *Pop. Mech.*, July, 1915, p. 103.
[52] *Elec. Rec.*, May, 1915, p. 18.
[53] *Pop. Mech.*, June, 1915, p. 893.
[54] *Elec. World*, July 17, 1915, p. 146.
[55] *Tech. World*, Apr., 1915, p. 226.
[56] *Municipal Jour.*, Jan. 7, 1915, p. 12.

signal. A power station has installed[57] a system of red lamps on the switchboard gallery which indicate when and where an individual is entering the compartments containing the dangerous high tension apparatus. Another central station uses red lights to indicate that the trolley rail of the ash conveyor is energized and therefore dangerous.

A novelty[58] in the way of a signal and projection light is a small lamp with a reflector, to be attached to an electric iron. The lamp is connected to the wiring inside the iron. It not only illuminates the cloth in front of the iron, but acts as a tell-tale in case the current is left on when the iron is not being used. Work is also being done on the development of small[59] pilot lamps for use at the needles of industrial sewing machines.

Flashlights.—Lately there has been an unusual development in the line of flashlights. One has been brought out exactly[60] like a fountain pen in appearance and size. It is provided with a pocket slip, is 5¾ in. (14.60 cm.) long and ¾ in. in diameter, and weighs only 1½ ounces (42.47 gr.). A modification of this idea[61] includes a pencil holder and the lamp can be operated with or without the pencil by means of a thumb slide in the pencil barrel. Still another type[62] similar to these employs the clip as a switch and is provided with a tongue depressor for use by physicians. A flashlight has also been developed which may[63] quickly and easily be attached to an ordinary dry cell.

WAR.

The great war furnishes an opportunity for the study and an incentive for the development of certain classes of illuminants. In its activity may be seen the application of the latest ideas regarding such factors as glare and the power of light of certain colors to penetrate fog. Active fighting is no more confined to daylight than business is, and the old type of romantic sorties under cover of darkness are made almost impossible owing to the frequent and brilliant flashes of illumination.

[57] *Elec. World,* June 12, 1915, p. 1556.
[58] *Elec. Mds.,* June, 1915, p. 165.
[59] *Elec. World,* June 12, 1915, p. 1557.
[60] *Elec. News* (Can.), Mar. 15, 1915, p. 37.
[61] *Elec. Rec.,* May, 1915, p. 18.
[62] *Elec. World,* May 15, 1915, p. 1258.
[63] *Elec. Rec.,* June, 1915. p. 21.

A recently designed signal device consists of a pair of binoculars over which is mounted a small parallel beam flashlight. The[64] battery for lighting the lamp is carried in the belt of the user. The average range of the instrument is about 3 miles (4.82 km.). An electric flashlight apparatus used by the British is similar in size and appearance to an ordinary camera. A large lens is provided at the front of the box and flashes are made by means of a telegraph key, which closes the lamp circuit.

Searchlights.—Traveling searchlights have been developed by the various nations at war.[65] Automobile trucks form the carriers and supply the power. The lights may be operated either on the truck or at a distance from it. The French have brought out a device for distance control employing the response of a tuning fork at the searchlight to a vibrating current sent from a contact breaker tuned in unison with the tuning fork. Gilded mirrors are being used instead of glass. Searchlights are used not only to detect the movement of the enemy,[66] but to blind troops when they are charging across the zone of fire and to discomfort the pilots of aeroplanes. Some of those used will throw an intense light for miles. Owing to the blinding and confusing effect, it has been found to be impossible to advance a body of troops in the face of strong searchlights, a practical illustration of the use and effect of glare.

Illuminants.—Besides searchlights a number of other types of illuminants are being used.[67] Among these may be mentioned the luminous cartridge which serves for the illumination of nearby fields and especially for investigating and exploring purposes. It is fired from its own pistol and has a range of action of about 200 meters and a luminous area of about 100 meters. It burns from 8 to 10 seconds. Similar to it, but with much larger luminous activity is the light-rocket which is discharged from a musket. It is fired distances from 45 to 900 meters and its intensity is so great that it lights up an area from 500 to 600 meters in diameter with an illumination almost as great as daylight and lasting from 30 to 40 seconds. Flares have been devel-

[64] *Sci. Amer.*, Oct. 24, 1914, p. 334.
[65] *Elec. World*, May 15, 1915, p. 1262.
Sci. Amer. Sup., Oct. 3, 1914, p. 209.
[66] *Sci. Amer. Sup.*, July 10, 1915, p. 23.
[67] *Jour. f. Gas.*, May 1, 1915, p. 238.

oped from fireworks and are similar to what are known as red, white, and blue fires used in Fourth of July celebrations. These are set out by sappers a distance in front of the battle line and are controlled from the headquarters of the officers. Ignited at intervals they keep the battle front illuminated throughout the night. Star bombs shot from mortars maintain an intense illumination for intervals as long as 20 minutes. For distance lighting a projectile similar to shrapnel is used, so constructed that it furnishes light after a definite time and at a predetermined height. Air bombs are constructed for use by aeroplanes. Torches have been developed which burn from 2 to 3 hours.

Profiting by conditions in the European war, the Secretary of War has directed the Engineering Corps to make an exhaustive study of and experiments with the use of searchlights, flares, star bombs, and other lights by troops in the field.

Portable Lamps.—The war has caused a considerable development in the way of pocket lamps in Germany.[68] In one type of hand lamp an ingenious mounting of the lamp in conjunction with a movable screen enables the light to be directed at various angles with the vertical and still be properly screened from observation. Another type[69] has an arrangement holding a pad and pencil with the light so concealed that only the pad is illuminated. Still another type[70] is in the form of a hemisphere, the inner surface of which is polished, and with the lamp may be used as a small searchlight.

Use is being made of acetylene for the illumination of portable hospitals.[71] Limitations in the supply of oil[72] have led in Germany to an effort to use coal gas in the lighting of trains in place of oil gas previously used. Among the other sources of light for ordinary purposes used in the war zones should be mentioned kerosene or paraffin oil lamps with incandescent mantles.[73]

Safety Lighting.—The danger from night raids by Zeppelins or other air craft has made it advisable to reduce the lighting in

[68] *Elek. Zeit.*, Oct. 22, 1914, p. 1030.
Elek. Anz., Mar. 28, 1915, p. 163.
Elek. Anz., May 9, 1915, p. 240.
[69] *Elek. Anz.*, May 16, 1915, p. 254.
[70] *Elek. Anz.*, May 23, 1915, p. 269.
[71] *Pop. Mech.*, June, 1915, p. 829.
[72] *Acet. Jour.*, April, 1915, p. 387.
[73] *Jour. of Gas Light.*, June 15, 1915, p. 659.

cities and towns in England and France. In Paris[74] in the neighborhood of the Eifel tower, lighting has been cut out almost entirely. As a sample of the orders for reduced lighting used in London may[75] be mentioned the following: In all brightly lighted streets, squares, and bridges a portion of the lights must be extinguished so as to break up all conspicuous groups or rows of lights and the lights not extinguished must be lowered in intensity, or made invisible from above by shading them or painting over the tops of the globes, providing that while thick fog prevails normal lighting may be resumed. Sky signs, illumined facias, illuminated lettering and powerful lights of all description used for outside advertising or for the illumination of shop fronts must be extinguished. Subsequently the above orders[76] were made more inclusive by prohibiting all lights outside of shops. This same order called for rear lights on vehicles. It is interesting to note that while we have had rear light ordinances for years it has taken war conditions to make the desirability of such lights apparent in London. As a result of the above requirements special reflectors have been developed.[77] In consequence of the lighting conditions it is claimed that there has been a large increase in fatalities caused by accidents.[78] Curious complications have arisen over the question of payment on the part of shopkeepers for exterior illumination which they are not receiving.[79]

Experiments have been made by one of the street car companies of London[80] to meet the requirements of reduced lighting and still furnish light enough to allow the passengers to read and conductors to cancel tickets. As a result of these experiments lamp shades used in the lower part of the car are dipped in a violet lacquer, thereby reducing the illumination by 50 per cent. In the upper part of the car a similar treatment is given and the shades arranged so as to throw the light across the car.

[74] *Ill. Eng.* (Lond.), June, 1915, p. 289.

[75] *Jour. of Gas Light.*, Dec. 22, 1914, p. 652.

[76] *Jour. of Gas Light.*, Dec. 17, 1914, p. 637.

[77] *Elec. Times*, Dec. 31, 1914, p. 609.

[78] *Elec. Times*, May 6, 1915, p. 399.
Ill. Eng., (Lond.), July, 1915, p. 300.

[79] *Jour. of Gas Light.*, Jan. 26, 1915, p. 182.

[80] *Elec. Ry. Jour.*, Dec. 26, 1914, p. 1398.

The dash lights are covered over with yellow paper. Experiments on dipping the lamps themselves were found to give unsatisfactory results.

The restrictive lighting regulations have emphasized the waste occurring in many show windows[81] and the desirability of considering the principles of illuminating engineering, in order to get good results. Interesting experiments[82] are to be carried out in London to diminish the inconvenience to the public due to the low public lighting. Street curb stones are to be painted white and householders are requested to paint similarly all door steps leading from sidewalks. Not only in the field of active operations but also at home[83] the question of illumination has been a matter of vital importance in the various camps formed to take care of troops newly recruited, or enroute from various parts of the country. Such camps cover an area of about 250 by 500 yards (228.6 by 457.2 m.) and contain 80 ordinary huts, 27 officers' huts, dining rooms, guard rooms, etc. About 1,200 lamps are employed.

The restrictions of lighting in so many towns in England has retarded the extensive use of the new types of high candlepower, high efficiency lamps. One of the effects of the war has been the recognition in Russia of the need of manufacturing her own incandescent lamps.[84]

THE PANAMA-PACIFIC EXPOSITION.

In its use of light the Panama-Pacific Exposition furnishes the most striking example of the progress of illuminating engineering that has ever been presented. It is an almost complete report in itself. For the first time in the history of such institutions a recognized illuminating engineer has been called in to take care of that branch of the work. For the first time in history the lighting of an international exposition was completely designed and charted before the buildings were erected, and the results bear eloquent testimony to the wisdom of that action. The latest types of street lighting both gas and electric are represented; the exteriors of the buildings are brilliant with "flood lighting"; the lighting of Festival Hall is a unique example of totally indirect

[81] *Elec.*, Dec. 11, 1915, p. 331.
[82] *Elec. World*, July 17, 1915, p. 158.
[83] *Elec. Eng.* (Lond.), Dec. 24, 1914, p. 649.
[84] *Elec. Rev.* (Lond.), Mar. 12, 1915, p. 346.

lighting; display lighting is exemplified in the wonderful scintillator system and in the Tower of Jewels; efforts to avoid glare are manifest on all sides; never has there been a more lavish use of colored light. And so this exposition stands as a living witness to the fact that illuminating engineering has "come into its own."

No attempt will be made to discuss all the novelties to be found in the lighting effects but reference will be made to some of the more prominent features of the illumination. More complete descriptions will be found by reference to the partial bibliography.[85] The basic idea back of the general illumination of the buildings was the desire to present the exposition at night in the same relative values of color and perspective in which it is observed by day. On this account the old outline-system of illumination in which incandescent electric lamps were used to outline the architectural features of the buildings was abandoned in favor of the new flood-lighting idea and particular attention has been paid to the ocular comfort of the sightseer while at the same time displaying for his appreciation wonderful effects produced by artificial light.

Four principal methods of illumination are employed. Opposite the walls of the exhibit palaces are luminous art standards bearing transparent shields, through which light is thrown onto the fascades. A second method of illumination is found in the concealed batteries of searchlight projectors which are used to flood the monumental sculptures, towers and minarets so that the minutest architectural details are visible. A third source of lighting is that of the concealed light which proceeds from the inner recesses of the columns which encircle the courts or are placed on the lofty Tower of Jewels and the Italian Towers commanding the entrance to the Court of Palms and the Court of Flowers. This method of lighting is also used in the vaults of archways and in other situations where it is desired to cast light upon the mural paintings. The great battery of 48 searchlight projectors each with a 36-in. (91.44 cm.) lens forming the "scintillator" makes a fourth source of illumination.[86]

In addition to these four principal sources of lighting there are

[85] *Light. Jour.*, Mar., 1915, p. 49.
Elec. World, Feb. 13, 1915, p. 391.
Elec. World, May 29, 1915, p. 1383.

[86] *Sci. Amer.*, Apr. 24, 1915, p. 378.

several minor sources. In various parts of the grounds are globes of white glass the light from which, at night, dissipates the shadows under the foliage. In the great central Court of the Universe two lofty columns of dense white glass are parts of the two fountains and are the principal source of the night illumination of the Court.

The striking effect of the Tower of Jewels was obtained through the use of specially designed[87] jewels cut from glass obtained in Bohemia and having an index of refraction of from 1.68 to 1.71. Each gem is suspended so as to be free to swing with air currents and has a little mirror placed within one-sixteenth of an inch of the apex, thereby increasing the number of spectra obtainable.

A noteworthy feature of the highway lighting is the use of 18 to 24-in. (60.96 cm.) globes carrying glassware of an absorption of approximately 50 per cent. and of a warm opal tint approaching amber. The illumination of the interiors of the buildings is accomplished by the use of 250 and 500-watt tungsten lamps in specially designed mirror reflectors. The lamps are located from 40 to 100 ft. (12.19 to 30.48 m.) above the floor, the energy is less than 2 watts per square foot (9.29 sq. dm.) and the foot-candles range from ½ to ¾ on the floor.

The first commercial installation of high pressure gas lighting in this country[88] and one which is said to show many improvements over foreign practise is to be found in the State and Foreign Building Section. The main artery for traffic is the Avenue of Nations and this and other streets and avenues in this section are lighted by high pressure two-mantle lamps enclosed in opal globes mounted single on the top of ornamental staff work columns. The lamps consume 21 cu. ft. (0.59 $m.^3$) of gas per hour, operate at 3 pounds (1.36 kg.) pressure, reduced at the standard from 30 pounds, and have a mean spherical candlepower of 408.

Installations of the same lamps have been made at all the entrances and exits of the grounds. At the entrances and exits of the main group of exhibition palaces and at the entrances of the courts, lamps of the low pressure type are used, mounted on

[87] *N. E. L. A. Bul.*, Apr., 1915, p. 250.

[88] *Amer. Gas Light. Jour.*, Nov. 30, 1914, p. 349.
Jour. of Gas Light., July 6, 1915, p. 17.

brackets. In the "Zone" gas standards 35 ft. (10.66 m.) high are placed at intervals of 100 ft. (30.48 m.) on both sides. There are 72 of these standards each carrying 5-mantle lamps with mercury valve distance control. Large decorative lanterns are hung about these lamps. Decorative effects[89] are obtained by the use of gas to produce tongues of flame from serpent-headed urns.

Some very spectacular effects are obtained[90] in the lighting of the glass dome of the Palace of Horticulture. These effects are made possible by the use of sets of specially designed lens plates, color screens and high-powered searchlights. The system used in lighting the interior of Festival Hall is a separate and distinct type of interior lighting which is unique. In a pit beneath the center of the floor are placed a number of searchlights which are set to throw their beams upward into a diffusing disk of thick glass sand-blasted on the under side, which distributes the light over the dome covering the auditorium and the dome in turn acts as a diffusing reflector.

The most bizarre and spectacular phenomena are produced by the "scintillator," over 300 effects having been worked out.

At the San Diego Exposition[91] neither the "flood-lighting" nor the "outline" system of illumination is used, but ordinary street lighting supplemented by light from the arches of the arcades. This has been found very satisfactory.

STREET LIGHTING.

Display Lighting.—A general survey of the progress in the lighting of streets shows that there has been a decided increase in ornamental lighting[92] for advertising purposes, or so-called "White Way" lighting. Among the cities where such installations have been made during the past year may be mentioned Portland, Ore.,[93] where a system has been placed on one of the business streets consisting of crossed structural steel arches bridging the crossings and supported on concrete columns. Each of these

[89] *Gas Inst. News*, Aug., 1915, p. 343.
[90] *Elec. Rev. and W. E.*, June 5, 1915, p. 1032.
Sci. Amer., Feb. 20, 1915, p. 180.
[91] *N. E. L. A. Bul.*, May, 1915, p. 340.
Elec. World, Mar. 27, 1915, p. 805.
[92] *Municipal Jour.*, June 24, 1915, p. 886.
[93] *Pop. Mech.*, July, 1915, p. 101.

arches is outlined by 192 incandescent lamps placed on the under side. "White Way" lighting has also been installed in Newark,[94] N. J., using lamps of 500 candlepower; in Louisville,[95] Ky.; in Lowell,[96] Mass., where 234 magnetite 6.6-ampere arc lamps have been used, placed 14.5 ft. (3.20 m.) above the sidewalk and with a maximum distance between units of 120 ft. (36.57 m.) and a minimum of 50 ft. (15.24 m.), lamps being located as far as possible on alternate sides of the streets; in Union,[97] N. J., where 40 gas-filled, 500-watt tungsten lamps were used; in Paterson,[98] N. J.; in Sioux Falls,[99] S. D., where 156 luminous arc 6.6-ampere lamps have been placed six to a block in a staggered arrangement; in Sandusky,[100] O., where 14 city blocks are involved and 380 gas-filled tungsten lamps of 250 candlepower each are mounted on two-light standards approximately 50 ft. apart; furthermore a complete lighting system for the city is being installed consisting of 920 60-candlepower and 100-candlepower lamps of the same type; in Cleveland, where 600 gas-filled, 20-ampere tungsten lamps are mounted on standards with a special type of glassware consisting of a refractor to give the desired distribution of illumination, and an enclosing globe with roughened surface which is designed to have a pleasing appearance without materially changing the distribution due to the refractor; in Charleston, W. Va.,[101] where 62 ornamental, luminous, 4-ampere arc lamps have been installed; at Malone, N. Y.,[102] where 400-candlepower, gas-filled tungsten lamps mounted on ornamental posts were installed; at St. Cloud, Minn.,[103] where the number of arc lamps was increased to 100 and changed to the luminous or magnetite type.

There is[104] a tendency to depart from the use of five-lamp standards for "White Way" lighting inasmuch as they are too prominent in the daytime. Preference to-day inclines toward a single

[94] *Elec. Rev. and W. E.*, Nov. 14, 1914, p. 954.
[95] *Elec. Rev. and W. E.*, Nov. 14, 1914, p. 954.
[96] *Elec. Rev. and W. E.*, June 5, 1915, p. 1039.
[97] *Elec. World*, June 26, 1915, p. 1697.
[98] *Municipal Jour.*, May 27, 1915, p. 740.
[99] *Light. Jour.* (U. S.), May, 1915, p. 98.
[100] *Elec. Rev. and W. E.*, May 22, 1915, p. 963.
[101] *Municipal Jour.*, July 22, 1915, p. 114.
[102] *Elec. Rev. and W. E.*, July 31, 1915, p. 180.
[103] *Municipal Jour.*, May 27, 1915, p. 729.
[104] *Elec. World*, May 22, 1915, p. 1328.

or at most a double-light unit with a comparatively high candle-power lamp. The introduction of the gas-filled tungsten street series unit has, in general, resulted in increasing[105] the candle-power used and not in decreasing the wattage. In addition to the improvement in efficiency the new construction has made possible an extension in the range of candlepowers available, thus giving greater flexibility to this type of lighting. The feasibility of replacing arc lamps with incandescents for street lighting has been agitated ever since the introduction of incandescent units of sufficient intensity to produce comparable results. The question has been re-opened since[106] the introduction of the high candle-power tungsten lamps. Numerous tests have been made and reports given on the relative merits of the two types of illuminants and on the relative cost of operation. But there are so many factors entering into the problem that it seems increasingly difficult to draw even general conclusions.

Street lighting progress in various cities,[107] aside from the special ornamental lighting previously mentioned, may be seen in the following record:

Portland, Ore.—Besides the ornamental lighting previously mentioned, 150 arc lamps have been added for general street lighting.

Tacoma, Wash.—Installation has begun on[108] 126 new ornamental standards each using a 250-watt gas-filled tungsten lamp.

San Francisco, Cal.—A few additional lamps, both gas and electric arc, have been installed, making a total of 3,423 arc lamps and 7,838 gas lamps. The most notable improvement has been the installation of 516 gas-filled, 250-candlepower tungsten lamps on the main thoroughfare leading to the exposition grounds. These lamps have been suspended from pipe brackets placed on the trolley poles, two to a pole, and at a height of 16 ft. (4.87 m.) above the sidewalk. The distance between poles is approximately 93 ft. (28.34 m.). It is expected that after the close of the ex-

[105] *N. E. L. A. Bul.*, Mar., 1915, p. 171.
[106] *Jour. f. Gas.*, Aug. 1, 1915, p. 777.
Elec. World, June 19, 1915, p. 1594.
Ibid., July 10, 1915, p. 109.
Elek. u. Masch., Feb. 7, 1915, p. 73.
Elek. Zeit., June 3, 1915, p 269.
[107] *Municipal Jour.*, June 24, 1915, p. 890.
[108] *Municipal Jour.*, May 27, 1915, p. 740.

position the number of lamps will be cut down as the illumination is much more brilliant than necessary under ordinary conditions.

Tuscan, Ariz.—A series street-lighting system has recently been put[109] in the business section consisting of 75 five-light standards equipped with four 60-candlepower and one 100-candlepower, 6.6-ampere, gas-filled tungsten lamps, and 75 one-light standards equipped with 100-candlepower similar units.

Dubuque, Ia.—585 600-candlepower and 34 400-candlepower gas-filled tungsten lamps have replaced,[110] with a decrease of 20 per cent. in total watt consumption, 470 series alternating current 6-6-ampere arc lamps.

Milwaukee, Wis.—The report on the street lighting survey authorized in 1914,[111] contains among others the following recommendations: that a total of 8,500 lamps be used; on residential streets 400-candlepower units hung 22.5 ft. (6.24 m.) high on center suspensions at the street corners, with 100-candlepower lamps at the curb midway between corners in blocks more than 420 ft. (128.01 m.) long; for business streets a pair of 30-ft. (9.14 m.) posts on opposite sides of the street every 180 ft., each post carrying two 1,000 candlepower lamps, semi-residential streets to be lighted by 400-candlepower units 360 ft. (109.72 m.) apart and outlying business streets by 600-candlepower lamps at the curb and on 180 ft. centers.

Chicago, Ill.—The principal changes during the[112] year have been the introduction of 300-watt, 20-ampere, gas-filled tungsten lamps in place of 450-watt enclosed alternating and direct current arc lamps and in underground work the replacing of 80-watt, vacuum type tungsten lamps with the 75-watt, 4-ampere series gas-filled type. The following table shows the number of lamps in service June 1, 1915, as compared with those in use June 1, 1914:

[109] *Jour. Elec. Power and Gas*, May 22, 1915, p. 407.

[110] *Elec. World*, June 19, 1915, p. 1635.

[111] *Elec. World*, June 27, 1914, p. 1480.

[112] *Elec. World*, May 8, 1915, p. 1173.
TRANS. *I. E. S.*, Apr. 30, 1915, p. 281.

	June 1, 1914	June, 1915
Flame arcs	10,283	10,021
300-watt gas-filled tungsten	—	9,020
Alternating current enclosed arcs	6,254	1,740
Direct current open arcs	1,272	—
4-ampere series vacuum tungsten	4,077	7,193
Gas, standard type	11,902	10,157
Gas, ornamental type	—	730
Gasoline	5,286	4,690
Rented flame arcs	1,161	1,302

Indianapolis, Ind.—Five miles of boulevard lighting have been installed[113]; 10-ampere, gas filled tungsten lamps have been used, four 250-candlepower units at the street intersections with 150-candlepower lamps at irregular intervals between corners and staggered.

Louisville, Ky.—Two hundred and fifteen gasoline lamps, which have been in service in the parks and along the parkways and operated only in the summer, are to be replaced[114] by 250 gas-filled, 100-watt tungsten lamps which will run throughout the year.

Detroit, Mich.—The lighting system has been extended by the addition of 1,186 additional 4-ampere, luminous arc lamps as well as 483 luminous arcs of the 6.6-ampere inverted type. The latter completes the illumination of eleven miles of boulevard. Forty series incandescent lamps have been installed in the alleys of one of the foreign settlements.

Philadelphia, Pa.—Additions during the year include 400 arc lamps 650 gas-filled, 400-watt tungsten lamps, 179 gasoline lamps and 300 gas lamps.

New York, N. Y.—Prior to Jan. 1, 1915, Greater New York was lighted[115] wholly by three types of units, the enclosed arc lamp, the 100-candlepower non-vacuum tungsten lamp and gas lamps. Since Jan. 1, the 300 to 1,000-watt multiple and 400-candlepower series type of gas-filled tungsten lamps have replaced 10,000 enclosed carbon and flaming arc lamps. In Queens and the Bronx about 5,000 non-vacuum 100-candlepower tungsten units have replaced gas. Approximately[116] 600, multiple, arc lamps in use on the bridges connecting the several boroughs have

[113] *Elec. World*, May 8, 1915, p. 1201.
[114] *Elec. Rev. and W. E.*, Feb. 20, 1915, p. 332.
[115] *Light. Jour.*, May, 1915, p. 108.
[116] *Elec. World*, June 19, 1915, p. 1639.

been replaced by the 300-watt, gas-filled tungsten units. So far these lamps have withstood traffic vibrations satisfactorily. Negotiations are under way[117] for a large number of 200-watt, non-vacuum tungsten lamps to replace gas lamps on many of the side streets.

Brooklyn, N. Y.—All direct current arcs have been replaced by 300-watt, non-vacuum tungsten lamps. At present, June, 1915, 2,000 are installed. Gas lamps are being replaced by 300-watt, non-vacuum tungsten units.

Montreal, Can.—An extension of the lighting system is being made by[118] the addition of 84 luminous, 6.6-ampere, arc lamps, on ornamental poles of special design placed 125 ft. (48.1 m.) apart.

Canal Zone, Panama.—In the Canal Zone permanent street lighting systems similar to those in use in Washington, D. C., are to be installed in[119] the principal towns. Gas-filled tungsten lamps probably of 100-watt size, 6.6-ampere series type will be used.

Great Britain.—The report[120] issued by the British Government on the use of gas during the year closing June 1, 1914 has been issued and shows an increase in the number of gas consumers in Great Britain of 357,411. The report also states that while the use of electricity for street lighting is increasing there are still 779,442 incandescent gas units in use.

Berlin.—The number of gas lamps in use for public lighting in Berlin, Mar. 31, 1914, was 43,780,[121] and increase of 2,324. As in previous years there has been an increase in high pressure lighting in the prinicipal streets. In the inner parts of the city, illumination has been strengthened by increasing the number of burners in a lantern, by increasing the number of many-flame low pressure inverted lamps, as well as by increasing the number of lamp standards. In Victoria Park the electric lighting has been improved by the addition of arc and metal filament lamps. There are still in use a small number of petroleum and spirit lamps.

Investigations.—The investigation of street lighting being carried on under the joint auspices of committees of the National

[117] *Cent. Sta.*, June, 1915, p. 367.
[118] *Elec. News* (Can.), May 1, 1915, p. 39.
[119] *Light. Jour.*, Apr., 1915, p. 89.
[120] *Amer. Gas Lt. Journ.*, Apr. 5, 1915, p. 217.
[121] *Jour. f. Gas*, Mar. 20, 1915, p. 143.

Electric Light Association and the Association of Edison Illuminating Companies and which was started last year is[122] still uncompleted. To properly interpret results already obtained requires a complete knowledge of the conditions and no attempt will be made to summarize them in this report. Another investigation of the factors connected with effective illumination of streets has been directed toward a study of the effect of glare on visual acuity. The method[123] of test consisted in making observations of a special visual acuity test chart first with the street lamps off and then under ordinary lighting conditions. Among the conclusions reached were that merely surrounding a brilliant source of light by a diffusing globe does not materially diminish blinding effects. Mounting heights less than 20 ft. (6.09 m.) should be avoided if possible and heights less than 15 ft. should never be employed. When the height is relatively low, the candlepower between the angles of 65° and 90° from the vertical should also be relatively low. So far as avoidance of glare is concerned there is no object in increasing the height beyond 50 ft. (15.24 m.). An excellent summary of technical data on electric street illuminants was presented at the 1915 convention of the National Electric Light Association.

OTHER EXTERIOR ILLUMINATION.

The continued improvement in illuminants is reflected in the spread of out-door-lighting of all kinds and the use of light more than ever before for a variety of purposes. Thus a real estate dealer arranges to have a new sub-division highly illuminated[124] and rapidly sells his lots to customers who have come out to view them at night. Improvements in distance lighting and control[125] have made feasible the employment of gas in places where its use had previously been considered impossible. A big extension is to be noted in the use of light for exterior advertising purposes.

Flood-lighting.—One of the most striking illustrations of the modern "flood-lighting" method of illuminating the exterior of

[122] TRANS. I. E. S., 9, 1914, p. 536.
Report of Committee on St. Light. *N. E. L. A.*, June, 1915. See also TRANS. *A. I. E. E.*, July, 1915, p. 1379.
[123] *Elec. Rev. and W. E.*, Mar. 6, 1915, p. 439.
[124] *Elec. Rev. and W. E.*, May 8, 1915, p. 856.
[125] *Gas Age*, July 1, 1915, p. 5.

buildings is to be found in the lighting of the Woolworth building[126] in New York City, which was disclosed to public view at the beginning of the year. It has been said that more light is provided for the illumination of the tower than is usually employed in lighting a city of 30,000 inhabitants. 600 automobile projector units fitted with 250-watt, gas-filled tungsten lamps are used to throw light on the structure from the thirtieth to the fifty-eighth story. These projectors are arranged so that some throw their light upward and the rest throw their light downward. Thus there is one continuous diffusion of light over the whole surface. The lamps throwing light downward are carefully screened so as not to be directly visible from the street. The most novel point of the installation, however, is at the sixtieth story called the "crow's-nest" or "lantern." It has been enclosed with diffusing glass and within are placed twenty-four 1,000-watt lamps. An automobile dimmer connected with these lamps continuously alters their intensity in an irregular cycle. Thus at one instant the glass surface of the lantern shows a deep red glow no brighter than the adjacent gilded structure, and again it flares up to a bright white light many times this brightness and visible for miles.

The flood-lighting idea has been much extended in[127] the illumination of advertising signs on billboards, water tanks, roofs of buildings, side walls and elsewhere. In such cases the effect is accomplished by directing a beam of light against the sign from some nearby convenient location; a new lighting unit of high intensity utilizing a parabolic reflector has been recently developed for this special purpose.

Lighting of Sports.—The lighting of courts for tennis and other sports has proved so satisfactory that the idea is being tried out in a number of different ways. A playground in a city park has been illuminated so that[128] its various amusements are available at night as well as by day. Five 750-watt, gas-filled tungsten lamps are used to light the football field while 1,000-watt units are used to illuminate the swings and gymnasium apparatus. These units are placed 20 ft. (6.09 m.) above the ground on goose-neck boulevard posts. A test was made at the Indiana

[126] *Elec. Rev. and W. E.*, June 5, 1915, p. 1048.
[127] *Elec. Merchandise*, Dec., 1915, p. 306. See also *Cent. Sta.*, May, 1915, p. 346.
[128] *Elec. World*, May 22, 1915, p. 1328.

State Fair grounds recently of[129] a system of illumination, in order to try out the practicability of automobile racing at night. The result was a complete success. Lights of the type used in contracting and railroad work for emergency operations at night, were placed at intervals about the track. Each light was supplied from its own cylinder of dissolved acetylene. In another case[130] an outdoor skating rink used for the sport of curling has been lighted by tungsten lamps installed on two lines of stray wires, extending the length of the rink, and about 35 ft. (10.66 m.) apart. Extra illumination is furnished at the ends over the goals. The lamps hang about 15 ft. above the surface of the ice.

A sign of progress[131] is to be noted in the installation of a lighting system on the celebrated wall which surrounds the block in Salt Lake City enclosing the famous Tabernacle and Temple. The wall is approximately 12 ft. (3.65 m.) high and will be lighted by high power lamps located every 50 ft. (15.24 m.).

Because of the scarcity of kerosene there has been an extension of gas and electric lighting in Germany,[132] alcohol and acetylene being adopted in the country districts.

INTERIOR ILLUMINATION.

The trend in interior lighting continues to be in the direction of protecting the eyes from excessive brightness.

Hotel Lighting.—A recently finished, and[133] what is claimed to be largest hotel in Europe, has been fitted throughout with the semi-indirect system of illumination. The lighting has been so arranged that corridor lights are independent of those in adjacent bed-rooms. In the dome of the rotunda court a novel plan has been adopted of introducing opal bulls-eyes, with a lamp behind each, into the risers which support the glazing of the dome. Around the dome cornice is a ring of lamps which are concealed from view at the floor level but throw a considerable volume of light upward into the dome. Some 6,000 lamps are used in this hotel. In England[134] the use of high pressure gas is being extended to factory lighting.

[129] *Sci. Amer.*, June 12, 1915, p. 587.
[130] *Elec. Rev. and W. E.*, Feb. 13, 1915, p. 311.
[131] *Elec. Merchandise*, Apr., 1915, p. 82.
[132] *Pop. Mech.*, May, 1915, p. 651.
[133] *Elec. Times*, June 24, 1915, p. 531.
[134] *Jour. of Gas. Lt.*, June 1, 1915, p. 506.

Municipal Buildings.—While a private enterprise is quick to see and adopt improvements in lighting sources and methods, the municipally controlled institution has in the past exhibited a decided inertia in this respect. A start has been made in Boston[135] to remedy this and the replacement of old types of lamps of low efficiency has already brought about a marked saving to the city. The change has been so satisfactory that one of the city engineers is to devote his entire time during this year to improving the lighting of buildings in the school, police and fire departments.

Office Buildings.—Heavy glass partitions which are translucent, substantial, sun-proof, and fire-proof, are being introduced as a[136] means of distributing sunlight through large office buildings, without lessening the privacy of the various offices. These partitions are built of clear glass units, 2 in. (50.8 mm.) thick, and either 6 or 8 in. square, which are reduced to translucency by impressed designs.

Hospitals.—That the educational work of the Society on the subject of color and glare is bearing fruit, is seen in the use of green and buff for the color of the walls in a large Western[137] hospital. White had always been used, but it was found, on trial, that the discomfort coming from the necessity of eye-adaptation on the part of surgeons looking up from their work, and seeing only white-clothed assistants and white walls was largely eliminated with the use of other colors. The effect on patients has also been beneficial. In another large city hospital a rather unique use of the mercury-vapor lamp is found in its employment[138] for examination of X-ray skyographs.

Street Railway Cars.—A growing recognition of the importance of proper lighting in every sphere of activity is illustrated in the[139] recent extensive tests conducted by a large municipal railway. A full sized template car was built and tested when equipped with direct, semi-indirect, and totally indirect systems of lighting. The general effect and appearance of each system under test were judged by comparison with present methods of car lighting for similar service. The effect of the light on the

[135] *Elec. World,* May 22, 1915, p. 1327.
[136] *Pop. Mech.,* June, 1915, p. 818.
[137] *Pop. Elec. and Mod. Mech.,* Dec., 1914, p. 644.
[138] *Elec. World,* June 5, 1915, p. 1475.
[139] TRANS. I. E. S., 1915, p. 227.

eyes was particularly noted by a large number of observers. The system finally adopted consists of a single row of 56-watt, bowl-frosted tungsten lamps placed symmetrically down the center line and equipped with opal glass reflectors. These lamps were supplemented by six 10-watt, all-frosted round bulb tungsten emergency lamps. One big unit was placed on each end-bulkhead of the car to bring up the illumination at these points. In the car as finally equipped the illumination averaged 5.94 foot-candles, at normal and 3.85 at 85 per cent. voltage, the energy consumption was 1.44 watts per square foot, effective lumens per watt 4.14 and the utilized efficiency 50.6 per cent.

Another street railway company is emphasizing[140] the "Safety First" principle by providing a light so placed as to directly illuminate the step of the street car. A practical application of signal lights has been adopted by[141] some of the theaters of Vienna. On the back of each seat is a small electric lamp which illuminates the seat number. As long as the seat is turned up, as it usually is when not occupied, the light is burning, but is shut off when the seat is turned down. By this means the use of ushers has been materially decreased.

Clock Tower.—A novel use for the method of indirect lighting is to be found in the illumination of clock dials in the new Boston Custom House.[142] Behind each dial is a chamber with white walls illuminated by a number of lamps. Numerals of the dial are in the form of slots set in concrete and the lights in each chamber are so arranged that no unreflected light passes through the slot. The effect is to make each numeral appear as if cut out from a piece of uniformly lighted paper.

An application of the "flood-lighting" idea was made[143] recently at one of the automobile shows where a machine was brilliantly illuminated by lights in two ornamental troughs hung by chains about 8 ft. from the floor, and 9 ft. (2.74 m.) in front of the car.

The art-glass dome is ordinarily associated only with the lighting of dining-rooms, but it has been added[144] to the long list of

[140] *Elec. Ry. Jour.*, Jan. 30, 1915, p. 247.
[141] *Pop. Mech.*, Apr., 1915, p. 568.
[142] *Pop. Mech.*, July, 1915, p. 75.
[143] *Elec. World*, May 15, 1915, p. 1255.
[144] *Elec. World*, May 22, 1915, p. 1315.

illuminants used to produce an attractive show window illumination.

Reflection.—Now that semi-indirect and totally indirect lighting systems are coming more and more into use, the effect of the walls and ceilings in reflecting light is of great importance. The results of considerable work on tests of the reflecting power of paints have been presented. The[145] colors examined ranged from white to dark buffs and greens. The highest coefficient obtained was 0.657 which was for a white oil paint of medium gloss. Less than one half of the samples tested showed coefficients above 50 per cent. and all of those that did so were of very light creamy or yellowish tones. A rather light olive color gave only 0.328.

Code.—Reference should be made to the very important work of the Committee on Lighting Legislation and the Factory Lighting Committee of this society, as a result of which a code on the lighting of factories, mills and work-places has been prepared.

GLOBES, REFLECTORS AND FIXTURES.

Having plenty of light available either from gas or electricity, manufacturers have increased the variety of materials used in making globes, reflectors and shades. At one extreme might be put the wicker basket. Provided with or without a lining, it is used suspended from the ceiling as a semi-indirect fixture; or inverted and covered with suitable material, it makes a shade for a table lamp. At the other extreme might be put the hammered brass bowl with or without glass inserts and used for either totally indirect or semi-indirect lighting. There is a growing use of floor lamps having very large shades and mounted on standards 5 or 6 ft. (1.52 or 1.82 m.) high. Such a lamp is replacing the old center table lamp for family reading and inasmuch as those using it can all have the light properly directed for reading purposes, it forms a step in the direction of eye protection. There is also a growing trend on the[146] part of architects to call for lighting fixtures which conform to the period of their surroundings.

In school rooms an increasing tendency toward the use of denser glassware with the semi-indirect lighting method is noticeable and in general for both direct and semi-indirect system the

[145] *Elec. World,* Jan. 23, 1915, p. 211.

[146] *Elec. World,* Apr. 3, 1915, p. 87?.

denser glassware is used. Furthermore the tendency towards constantly increasing candlepower in small units has led to a greater use of diffusing media such as marble and alabaster, and to fixtures carrying several lights burning upright with small semi-indirect shades. The use of cloth for shades is growing and an umbrella manufacturer has developed[147] a collapsible shade of cretonne, which can be folled up, when not in use, for packing or storage purposes.

A novel arrangement has been brought out in England[148] for converting a dining room fixture into a combined direct and semi-indirect unit. A double cone of white silk is employed in conjunction with the common "corona band" so that the lamp occupies a position in the lower cone, when the fitting is at the usual height, giving light directly downward, while at another height the lamp moves up into the upper cone, with the light directed toward the ceiling.

For the modern very large office building an equipment of specially designed fixtures is not uncommon. In one case of this kind[149] a fixture was developed which can be utilized either for direct, semi-indirect or totally indirect lighting. There is evidence[150] of a considerable increase in the employment of the semi-indirect type of fixtures for gas.

A great advance has been made in gas fittings.[151] The old "goose neck," fastened with a wire, is being replaced by straight pipe tubing with gas-tight adjustable couplings, which make a variety of brackets available.

Reflectors have been developed for converting[152] the ordinary gas "arc" as used in stores and warehouses into a semi-indirect unit, thus meeting the demand for this type of lighting without the necessity of scrapping former fixtures. The advent of the 100-watt, gas-filled tungsten unit has caused the development of prismatic and mirrored reflectors for use in show-window lighting.

[147] *Light. Jour. and Eng.* (Lond.), Feb., 1915, p. 81.
[148] *Ill. Eng.* (Lond.), Mar., 1915, p. 103.
[149] *Elec. World*, Feb. 20, 1915, p. 490.
[150] *The Gas Age*, Jan. 1, 1915, p. 8.
[151] *Light. Jour.* (U. S.), Dec., 1914, p. 281.
Proc. Amer. Gas Inst., vol. IX, 1914, p. 886.
[152] *Amer. Gas Lt. Jour.*, May 3, 1915, p. 286.

In lighting fixtures of ornate design and equipped with electric candle or candelabra lamps the use of ordinary key or pull sockets for individual lamp control is often undesirable and esthetically objectionable. A rotating switch has been devised to meet[153] this condition, which is operated by turning an outer sleeve forming part of the candle. The replacing of arc lamps by the new high efficiency tungsten lamps has resulted in an[154] adaptation of the fixtures of the former to act as housings for the latter. The principal change needed is the introduction of baffle plates to prevent the entrance of rain without hindering the ventilation. For all classes of outdoor lighting by electricity, fixtures have been designed which include[155] not only adaptability to series or multiple circuits, to pole or cross-span suspension, but also ventilating and enclosing glassware if desired, so that a complete equipment is available in one fixture.

A reinforced-concrete lighting standard of attractive design and appearance is being installed[156] in a number of California cities including beach resorts, where metal standards have suffered severely in the past owing to the action of salt air.

PHOTOMETRY.

The measurement of light sources differing in color value continues to interest the photometrist. Developments have followed two general lines, one the elimination of the color difference, thereby reducing conditions to those of ordinary photometry, the other the use of the flicker photometer which has not yet been generally accepted as a solution of the problem.

Secondary Standards.—At the National Physical Laboratory in England there has been completed and described[157] a careful and exhaustive research having for its object the establishment of a set of standards matching in color lamps operating at the various efficiencies in ordinary use. In this research the color problem was met by using the so-called "Cascade" method in which a lamp at a given watts per candle is measured against one whose watts per candle differs by an amount which will make the

[153] *Elec. Rev. and W. E.*, May 29, 1915, p. 1005.

[154] *Elec. World*, May 1, 1915, p. 1131.

[155] *Elec. Rev. and W. E.*, July 24, 1915, p. 167.

[156] *Elec. World*, Apr. 3, 1915, p. 874.

[157] *Phil. Mag.*, July, 1915, p. 63.

color difference small enough not to be objectionable. Check measurements were also made in which the maximum color difference was encountered. The experience gained from these and other comparisons was that whereas an observer may be relied upon for constancy of judgment in measuring with an ordinary contrast photometer sources differing by a small amount in color value, the same constancy in judgment was not obtainable where the color differences were large. Efforts were made to use the flicker photometer but the results were not satisfactory and the accuracy was of a different order of magnitude from that found with the other method.

Color Difference.—It is rather interesting to note that elsewhere[158] in observations on color differences made with a flicker photometer and extending over a year, individual observers reproduced their results with very few exceptions.

The color screen method of eliminating the color difference in heterchromatic photomery has been extended by the development[159] of a blue solution, which in varying degrees of saturation will provide a color match between a standard carbon lamp and another lamp operating at any watts per candle from 3.1 to 0.5. An alternative for[160] the color absorbing solution in eliminating color differences is suggested in a new photometer using polarized light. It is based on the rotation of the plane of polarization by a quartz plate and the fact that this rotation is different for light of different wave-lengths.

Flicker.—By applying to a modified form of the Conroy photometer[161] an oscillating platinized mirror and adding an optical wedge having its density gradient vertical and different by two per cent. from top to bottom a new flicker-photometer has been developed. Another arrangement[162] for a flicker-photometer consists in a modification applicable to the ordinary Lummer-Brodhun photometer head. A tube, replacing the ordinary eyepiece, carries a rotating prism. Means are provided for illuminating the surrounding field and for accurate speed control.

[158] TRANS. I. E. S., Apr. 30, 1915, p. 207.

[159] TRANS. I. E. S., Apr. 30, 1915, p. 253.

[160] *Phys. Rev.*, July, 1915, p. 64.

[161] *Phys. Rev.*, 4, 1914, p. 477.

[162] *Light. Jour.*, May, 1915, p. 111.

A theory of the flicker-photometer has been presented in[163] which the behavior of the instrument is deduced directly from the relationship of critical freqency and illumination. It is assumed that a fluctuating stimulus is transmitted as a considerably dampened fluctuating impression whose form and amplitude can be calculated by using the Fourier linear diffusion equation. The same line of reasoning is used to explain the relationship of color flicker to brightness flicker. Further work[164] has also been done on the question whether results in color photometry obtained by the flicker method and the acuteness of vision method are the same. The data obtained in these experiments indicated they are. A Lummer-Pringsheim spectro-flicker-photometer was employed and experiments made with foveal vision and portions of the retina lying 20° to 30° outside the direct line of sight. Means have been provided,[165] using colored absorbing media for correcting an abnormal eye. It is claimed that by the practical application of this method to the flicker-photometer it is possible to equip any observer so that he will read correctly color differences of a given type; and to equip a color blind observer so that he will not only read such differences correctly, but also measure other color differences with no more uncertainty than a random observer of "normal" vision will do.

Integrating Sphere.—At the last convention there was quite a discussion on the best paint to use for the inner diffusing surface of an integrating sphere. An elaborate research was undertaken in Germany[166] to decide not only this point but also the best material of which to make the sphere itself. The results indicated that iron plate is to be preferred to zinc for the construction material and that zinc white as the diffusing surface gives the best results.

New Instruments.—In the photometry of phosphorescent gases and certain phosphorescent solids, the light to be measured is of rapidly diminishing intensity. In order to ascertain the errors occurring in the measurement of such a light a modification of the ordinary photometer has been devised[167] in which the essential feature is a sliding carriage supporting one of the lamps and

[163] *Phil. Mag.*, May 28, 1915, p. 708.
[164] *Ann. d. Phys.*, Aug. 14, 1914, p. 105.
[165] TRANS. I. E. S., Apr. 30, 1915, p. 259.
[166] *Elek. Zeit.*, Mar. 25, 1915, p. 37.
[167] *Phys. Rev.*, Oct., 1914, p. 289.

capable of being set in to and fro motion at uniform velocity in the photometric axis. Means are provided for recording the position of the carriage while in motion. Using this instrument an investigation showed that errors as high as 15 per cent. or more, and apparently due to retinal fatigue, may occur in the photometric measurement or phosphorescent decays.

A new portable illumination photometer has been brought out[168] which is a modification of the Weber type and much more compact. Another illuminometer[169] has been described for use where rapid and rough measurements of light intensity are desired. In this instrument a screen of black silk illuminated from the rear is viewed in comparison with tinted sectors, on which falls the illumination to be measured. The intensity of the light from the comparison lamp is controlled by an iris diaphragm. As a quick means of determining the various energy relations in tungsten lamps, a direct reading instrument has been devised[170] using data presented at the last convention.[171] It is made up of volts, watts per candle and per cent. candlepower scales. The volt scale has a range from 94 to 166 volts, while the watts-per-candle scale limits are 0.70 and 2.05. Knowing any two relations the other may be calculated within the range of the instrument.

A study[172] of the rotating sectored disk when used in photographic photometry has shown that an intermittent exposure, such as that given by the disk, has the same integral effect as a continuous exposure for the same period. The conclusion for ultra-violet radiation is the same as that found for visible radiation. Experiments were made on a variety of plates and it was found that the results were independent, within wide limits of the rate of rotation of the sector and of the period of exposure.

Gas-filled Tungsten Lamps.—The measurement of the candlepower of the gas-filled tungsten lamps has developed some entirely new problems in photometry. Thus it was early discovered[173] that both the watts consumed and the candlepower of the lamp vary when the lamp is rotated at different speeds. One set of

[168] *Elec. World,* Jan. 9, 1915, p. 85.
[169] *Elec. World,* Jan. 16, 1915, p. 170.
[170] *Jour. of Frank. Inst.,* July, 1915, p. 102.
[171] TRANS. I. E. S., 9, 1914, p. 734.
[172] *Ann. d. Phys.,* Nov. 3, 1914, p. 801.
[173] TRANS. I. E. S., 9, 1914, p. 1024.

experiments[174] showed that for any change in speed, while the change in candlepower was roughly ten times the change in current but always in the opposite direction, and regardless of the position of the lamp, the absolute change in candlepower with the lamp in the position of tip up is about twice the change with the tip down and similarly for the absolute change in the current. From the photometric standpoint a favorable condition was discovered in that, for a given position of the lamp, the current and therefore the candlepower return to the stationary value at the same speed. If then, a gas-filled lamp is photometered in the position tip down, while rotating at the particular speed which gives the same current value as when the lamp is stationary, the mean horizontal candlepower as measured will be free from errors due to rotation.

Various explanations have been offered for these phenomena. It has been suggested that they may be due to variations in the contacts between the filaments and the anchor wires; to changes in the currents of gas about the filament; to the lengthening of the helically coiled[175] filament, thus changing its resistance; to a cooling effect due to the action of the external air in the bulb.

Photo-electric Cell.—In astronomical photometry[176] work is being done, with some success, looking toward increasing the sensibility of the photo-electric cell. A null method of using photo-electric cells has been devised which,[177] it is claimed, does away with the so-called "dark current" without in the least reducing the sensitivity.

Pentane Standard.—A redetermination at the National Physical Laboratory[178] of the constants of the Pentane lamp gave the following as the equation of the candlepower:

$$\text{C. P.} = (\,(1 + 0.0063\,(8 - e) - 0.0008_5\,(760 - b)\,)$$

e being the humidity in liters of water vapor per cubic meter of moist air, and b the barometric pressure in millimeters. Evidence was obtained that there exists a temperature coefficient in the case of the pentane lamp, a point which had been raised previously at the Bureau of Standards. Apparently the temperature

[174] *Elec. World,* Dec. 26, 1914, p. 1248.
[175] *Elec. World,* Jan. 9, 1915, p. 78.
[176] *Science,* June 4, 1915, p. 810.
[177] *Phys. Rev.,* July, 1915, p. 66.
[178] *Phil. Mag.,* July, 1915, p. 80.

and humidity effects act against one another and in practise it is the difference between the two which is operative. It is suggested that if work of the very highest accuracy is to be carried out with flame standards under abnormal humidity conditions, the combined humidity temperature coefficient should be determined for the locality in which the work is to be conducted.

Radiation.—Experiments[179] on the emissivity of metals at high temperatures have given results indicating a change in the emissivity of platinum for wave-length $\lambda = 0.65\mu$. This fact if verified would influence the constancy of the Violle standard of light.

Two investigations have been made during the year on the determination of the visibility of radiant energy. One covered[180] the whole visible spectrum going further into the red and voilet than heretofore. The other[181] dealt with the red end of the spectrum only, results being obtained out as far as $\lambda = 0.770\mu$.

Calculation.—Methods of calculating the illumination produced by a direct-lighting source are numerous and well known. But in the case of a totally indirect or semi-indirect unit the calculation is decidedly modified. A method has been proposed[182] in which it is necessary to know only the photometric curve, the coefficient of reflection for the secondary source (usually the ceiling), the distance of the unit below the ceiling and the height of the ceiling above the plane of illumination. Roughly the method involves the consideration of the ceiling as a secondary light source considered as made up of a series of circular annuli or rings of uniform intensity of illumination. The effect of each ring is calculated independently.

Nomenclature.—Considerable attention has been given to the subject of nomenclature during the past year. It has been proposed[183] that the word "lambert" be used in referring to brightness in lumens per unit projected area. The "lambert" is interpreted as the equivalent in appearance to the eye of a surface source emitting one lumen per unit area in accordance with Lambert's cosine law. The following resolution which was sub-

[179] *Phys. Rev.*, Dec., 1914, p. 547.
[180] *Phil. Mag.*, Feb., 1915, p. 301.
[181] *Phys. Rev.*, July, 1915, p. 68.
[182] *Elec. World*, June 5, 1915, p. 1463.
[183] *Elec. World*, Mar. 29, 1915, p. 715.

mitted by the Committee on Nomenclature and Standards has been approved[184] by the Council of the Society:

Resolved, That it is the opinion of this Committee

(*a*) That the output of all illuminants should be expressed in lumens.

(*b*) That illuminants should be rated upon a lumen basis instead of a candlepower basis.

(*c*) That the specific output of electric lamps should be stated in lumens per watt and the specific output of illuminants dependent upon combustion should be stated in lumens per British thermal unit per hour.

PHOTOGRAPHY.

Sources.—The use of gas light[185] for taking pictures is increasing and special mantles have been designed for the purpose. In order to facilitate the use of the high intensity gas-filled tungsten lamp[186] in photographic portrait studios, a colored glass screen has been developed which reduces the luminous intensity of the light to one-third its ordinary value without appreciably reducing the actinic value for ordinary plates. For convenience this glass has been incorporated in the lamp bulb. Thus high candlepower lamps may be used without producing an uncomfortable glare. It has been found possible[187] to use such lamps, screened as described, in moving picture production studios. In a big western moving picture plant[188] there is used a combination of mercury-vapor lamps and 2,000-candlepower tungsten gas-filled units of the type just mentioned. In Germany[189] tests have been made on the use of the gas-filled tungsten lamp for photographic work at voltages higher than normal, thus giving greater actinic value. This same idea has been proposed and experimented on[190] in this country.

Tests have been made on[191] the density of the photographic image produced under fixed conditions of distance and time by

[184] TRANS. I. E. S., 9, p. 2, 1914.
[185] *Gas Age,* Mar. 15, 1915, p. 304.
Light. Jour. (U. S.), Dec., 1915, p. 281.
Proc. Amer. Gas Inst., vol. 9, 1914, p. 886.
[186] *Elec. World,* Nov. 14, 1914, p. 950.
[187] TRANS. I. E. S., No. 2, 1915, p. 166.
[188] *Elec. World,* July 17, 1915, p. 137.
[189] *Zeit. f. Beleu.,* Mar., 1915, p. 33.
[190] *Elec. World,* Nov. 14, 1914, p. 950.
[191] *Elec. World,* Nov. 14, 1914, p. 956.

the light from different types of arc lamps under various conditions. The lamps tested were of the alternating current and direct current enclosed carbon and flaming arc types operated at various currents. The results showed that the highest actinic efficiency was obtained by the 220-volt, enclosed carbon arc; next in value were respectively, the alternating current and direct current 110-volt, flaming arcs with electrodes designed particularly for photographic work.

A photographic paper has been developed[192] on which portraits may be reproduced directly without the preparation of the usual negative. For operation with artificial illuminants the paper is treated with a dye which makes it more sensitive to yellow light. The pictures are mirror images of the original.

LEGISLATION.

Calorific Standard.—The Illinois Commission has ruled[193] that in all parts of the state excepting Chicago a calorific standard of 565 B. t. u. for gas shall be used. Chicago is to remain under the candlepower standard. The calorific standard has been adopted by the Maryland Public Service Commission.[194] A heating value of 600 B. t. u. is specified. It was estimated by the Commission that in the state generally only 6 to 10 per cent. of the gas used is burned in flat flame burners. The use of the calorific standard in gas undertakings does not seem to be growing rapidly in England.[195] Only eight companies have applied for parliamentary authority during the session of 1915. Four of these companies applied for a 500 B. t. u. standard.

Glare.—Extremely bright lamps are no longer allowed on residential streets, especially in front of isolated stores, in Washington, D. C.[196] Regulations adopted prohibit the use of lamps exceeding 100 candlepower on streets other than business streets. They also require a minimum height of 15 ft. (4.57 m.) for all private lamps supported from sidewalks, and that such lamps are to be enclosed in opalescent globes in order that the eyes of passers-by shall be protected from glare.

[192] *Elec. World,* Jan. 16, 1915, p. 190.
[193] *Proc. Amer. Gas Inst.,* vol. 9, 1914, p. 373.
[194] *Jour. of Gas Light.,* May 24, 1915, p. 463.
[195] *Amer. Gas Light Jour.,* Feb. 1, 1915, p. 73.
[196] *Elec. World,* Oct. 10, 1914, p. 700.

In December last[197] the War Department issued regulations ordering all fishing fields to be protected by a marine lantern of recent invention using acetylene as the illuminant. These lanterns, capable of 23 days' service, are arranged to give an in-shore and out-shore light to warn vessels that the areas thereabout comprise fishing pounds and are not open to navigation. Already a number of these lights have been placed.

A bill has been introduced[198] in the Utah legislature providing for the creation of special lighting improvement districts, under which the property owners on any street or sub-division may petition the city commission to create such districts and to install therein lighting systems.

Safety.—The Ottawa (Canada) City Council have recently[199] taken up the matter of all-night lighting of public buildings used for residence purposes. A by-law has been passed providing that the stairs, halls and corridors of all apartment houses, hotel and lodging houses must be lighted from sunset to sunrise.

In places where public safety demands it, there is a growing tendency on the part of municipal authorities to require two independent systems of illumination so that in case of failures on the part of either the other will be available.

Headlights.—The Public Service Commission of Vermont has issued an order[200] concerning the use of headlights on locomotives. Railroad corporations doing business within the state are required to equip engines with headlights of not less than 2,500 apparent beam candlepower when measured with the aid of a reflector, rated in accordance with the average of the center readings between 500 and 1,000 ft. (304.80 m.) ahead and upon a reference plane 3 ft. (0.91 m.) above the rails. In Nevada an amendment to the electric headlight law has been passed,[201] providing that any electric headlight "which will pick up and distinguish an object the size of a man dressed in dark clothing on a dark and clear night at 1,000 ft." will be deemed equivalent to a 1,500-candlepower headlight measured without reflector. Legislation

[197] *Acet. Jour.*, Feb., 1915, p. 305.

[198] *Elec. Rev. and W. E.*, Feb. 27, 1915, p. 376.

[199] *Elec. News* (Can.), Apr. 1, 1915, p. 38.

[200] *Railway Age Gazette*, Jan. 22, 1915, p. 127.

[201] *Railway Age Gazette*, Jan. 22, 1915, p. 123.

regarding headlights for motor vehicles has also been passed in New Jersey.

ILLUMINATING ENGINEERING IN GENERAL.

Daylight Saving.—By adopting eastern standard time Cleveland, Ohio has added one hour to the period of daylight. The result[202] has caused a renewed interest in the so-called "daylight saving movement" in the middle west. In Holland also this movement is being agitated.[203]

The use of light sources imitating daylight is growing[204] and has been found advantageous not only in clothing, painting and wall paper stores and factories, but also in printing and lithographing establishments, paper mills, oil refining plants, cigar factories, etc.

It has been proposed[205] to add to the numerous collections in Berlin a museum of illuminating appliances in which the development from the 17th century of lamps and other devices for street lighting will be shown.

Luminous Efficiency.—Values of the radiant luminous efficiencies (ratio of the energy radiated evaluated according to its effectiveness in producing the sensation of light to the total energy radiated) of various light sources have been determined using the method which employs an absorbing solution whose transmission curve is the same as the luminosity curve of the eye.[206] Among the results obtained were:

4 w.p.c. carbon lamp	0.43
0.8-ampere Nernst filament	1.08
6.6-ampere gas-filled tungsten at 0.65 w.p.c.	2.93
Ordinary vacuum tungsten at 1 w.p.c.	1.99
Open burner, gas	0.9
Incandescent mantle, gas	0.5 to 1.2
1.7 ampere mercury arc, Pfund type	30.0

A new experimental determination[207] by two different methods gives for the mechanical equivalent of light a mean value of 0.00162 watt per lumen.

[202] *Elec. World*, Jan. 2, 1915, p. 59.
[203] *Jour. Gas Light.*, Jan. 5, 1915, p. 16.
[204] *Elec. World*, July 10, 1915, p. 71.
[205] *Jour. Gas Light.*, May 4, 1915, p. 292.
[206] *Phys. Rev.*, Mar., 1915, p. 208.
[207] *Phys. Rev.*, Apr., 1915, p. 269.

Physiology.—Further work has been done on[208] the effect on the eye of ultra-violet light. It has been shown that where the protein in the lens of the eye has been modified by the action of excess sugar in the body fluids, or by the action of salts of calcium, magnesium, silica and the like, ultra-violet radiation may cause cataract, but that unless this abnormal condition exists cataract is not caused by this form of radiation.

Music and Color.—Several attempts to correlate music and color have been made in the past. A Russian composer having written a score in which was included a part to be rendered by various colors; a "color organ" was devised for use in a recent presentation of the composition.[209] Incandescent lamps in reflectors and equipped with color-filters formed the light source. The screen was composed of strips of gauze of various weights, mounted vertically and 8 by 10 ft. (2.43 by 3.04 m.) in size. The lightest sheet was placed at the front, each succeeding one back of it being heavier. The rear gauze was heavy enough to reflect the light thrown on it. The deepest colors were thrown on the back and the lighter colors were thrown on the front gauzes. The color equivalents of the tone scale were as follows: C, red; D, yellow; E, pearly blue; A, green; B-flat, steel gray; together with intermediate values. Color organs are not new,[210] several having been constructed in recent years. The largest screen used has been 30 by 50 ft. (9.14 by 15.24 m.).

International Commission.—At the meeting of the National Illumination Committee of Great Britain held early in the year[211] there was considered the question of "Rating of Light Sources in Candlepower or Consumption," and the following resolution was passed and transmitted to the Secretary of the International Commission on Illumination.

> It is desirable that a uniform international method be adopted for rating and marking all sources of light. It is recommended by the National Illuminating Committee of Great Britain that the matter be considered at the next session of the International Commission on Illumination; and the administration of that Commission is asked to take the necessary steps to bring this resolution to the knowledge of the different national committees, with the view to their co-operation.

[208] *Elec. World*, Apr. 19. 1915, p. 912.
[209] *Sci. Amer. Supp.*, June 26, 1915, p. 408.
[210] *Sci. Amer.*, July 24, 1915, p. 79.
[211] *Jour. Gas Light.*, Feb. 9, 1915, p. 326.

LITERATURE.

The war has seriously interferred with many foreign publications having articles on illumination. The French Journal, *Science et Art de l'Eclairage,* has apparently suspended publication and other French and German journals were compelled to omit some issues, although they are now appearing regularly. Among the books published during the year should be mentioned:

Modern Illuminants and Illuminating Engineering, by L. Gaster and J. S. Dow. New York, The MacMillan Co., 1915.

La Lumiere Electrique et ses Differentes Applications du Theatre, by V. Trundelle. Paris, H. Dunod and E. Pinat.

An Introduction to Color Vision, by Dr. J. H. Parsons. Cambridge University Press, 1915.

A RESUMÉ OF THE PHYSICAL, PHYSIOLOGICAL AND PSYCHIC PHASES OF VISION.*

BY NELSON M. BLACK, M.D.

Synopsis: This paper is a compilation in brief of the present day theories as to the processes involved in the visual act, considered under the physical, physiological and psychic phases of vision.

Generally speaking the visual act may be considered as that process whereby light, color and form are recognized by the visual apparatus. The complex act of seeing is best studied by dividing it into three distinct phases as suggested by Lohmann: a physical phase concerned with the refraction and focusing rays of light, emanating or reflected from a visible object, to form an image on the visual surface; a physiological phase consisting in the transformation of the light stimulus into a nerve impulse. These two factors alone will not induce sight, they must be supplemented by the third, or psychic, phase before percipient vision results.

PHYSICAL PHASES.

The visual apparatus consists of three essential parts: (1) the eyeball with its contents; (2) the optic nerve, and (3) the visual centers of the brain.

The eyeball may be compared with a camera in that it contains a diaphragm shutter and a lens, or, focusing system, and has to do with the physical phase of vision. The optic nerve terminals act as the sensitized background of the camera and the nerve fibers conduct the excitations produced during the physiological phase to the various centers in the brain which have to do with the psychic phase in the recognition of light, color and form.

The structures of the eyeball concerned in the physical phase are the *cornea* (Fig. 1) which is situated at the anterior pole of the eyeball and differs from the dense, pearly white, semi-opaque protective scleral coat of which it is a part, in that it has been specialized to admit light into the interior of the eye. It is very

* The Illuminating Engineering Society is not responsible for the statements or opinions advanced by contributors.

transparent and has a refractive index (1.337) slightly higher than that of water. Its two surfaces being so nearly parallel, the course of light rays is not appreciably altered in passing through it.

Back of the cornea, in an especially prepared chamber filled with a fluid of about the consistency of water, in which it can operate with greatest ease, is the diaphragm shutter or *iris*. This important part of the visual apparatus is a specialized portion of the middle, or, *choroid coat,* which furnishes nourishment to the other structures of the eye as it carries the blood

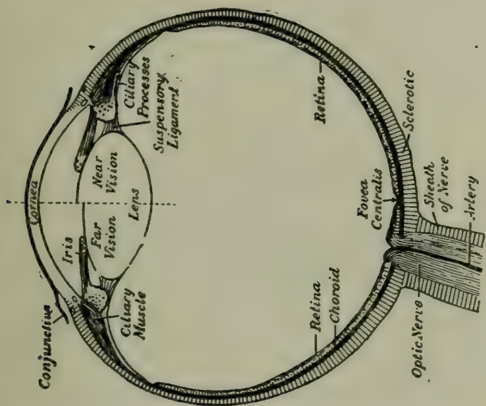


Fig. 1.—Schematic cross section of eyeball.

vessels. This coat also is deeply pigmented and shuts out extraneous light. The iris, which is opaque owing to the deposits of pigments of different color in its substance, contains circular muscular fibers for making the pupil smaller and radiating fibers which act in opposition. The inner or pupillary edge of the iris is separated from the *lens* or focusing system by a thin layer of fluid known as the *aqueous humor.*

The lens is an elastic crystalline body held in suspension between two layers of thin transparent membrane, the *lens capsule,* which meet at the periphery of the lens and is attached to another specialized portion of the choroid coat, called the *ciliary* body which regulates the focusing power of the lens by controlling its polar diameter, a process known as accommodation.

When the ciliary muscle is in a state of rest, the tension of the suspensory ligament acting on the lens flattens it to such an extent, that provided the refraction of the eye be normal, parallel rays of light falling on the cornea are brought to a focus on the retina. Rays from any nearer point are divergent when they strike the cornea, and the refractive power of the lens at rest is only sufficient to focus them at a point behind the retina. When, however, the circular muscle contracts, the suspensory ligament relaxes, and the lens, by virtue of the elasticity of its capsule, changes its shape and thereby increases its refractive power. The result of this is that the divergent rays of light can now be brought to a focus upon the retina. (Lohmann.)

The lens fits into a saucer-like depression of the *vitreous body*. This is a clear jelly like substance having a refractive index (1.3365) nearly the same as water, surrounded by a very delicate perfectly transparent capsule, the *hyaloid membrane*. The function of the vitreous body, which occupies about two thirds

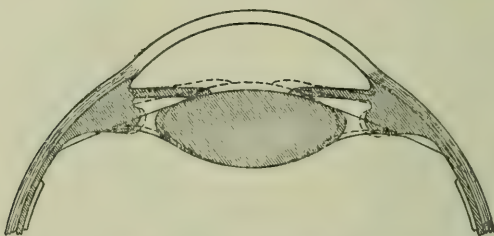


Fig. 2.—Changes in the lens during accommodation.

of the contents of the eyeball, is of considerable importance as it helps maintain the shape of the globe and holds the lens firmly in position.

Surrounding about four fifths of the vitreous body is the *retina* or what is commonly called the inner or third coat of the eye. In reality this so called coat is an outgrowth of the brain and consists of a spreading out of the fibers of the *optic nerve* over the entire back four fifths of the eye. By process of evolution this tissue has become a highly specialized nervous structure possessing the power of transforming impinging rediations of known wave-length into nerve stimuli. These excitations are transmitted by the fibers of the optic nerves, which each contain approximately 1,000,000 fibers, to the visual centers of the brain.

The retina or eye ground is the receptive layer of the visual

apparatus corresponding to the sensitized plate of the camera upon which the images of external objects are constantly being formed.

The fibers of the optic nerve upon reaching the interior of the eye spread out in all directions and then turn back in the direction they entered, Fig. 3. Each individual fiber is connected with a cell called a *ganglion cell, c,* Fig. 3. From these ganglion cells other fibers pass outward to so-called *bipolar cells,* the outer poles of which end in many branches or *arborizations,* Fig. 3, as they are

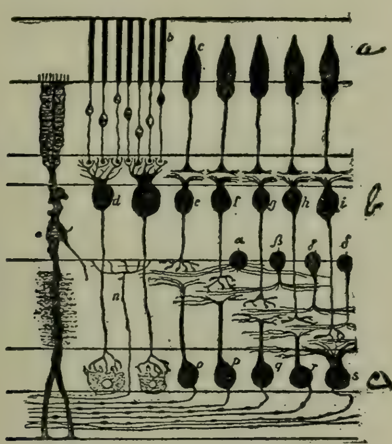


Fig. 3.—Schematic representation of distribution of nerve connections in retina.

called, which connect with the branches of other bipolar cells, b, Fig. 3. From these arborizations fibers extend vertically outward which end in a series of peculiar bodies called the *rods and cones,* a, b, Fig. 4. These are the terminals of the optic nerve fibers, and seen from above form a mosaic pattern, composed of about 5,000,000 minute disks, which differs in various portions of the retina. It is particularly noticeable that 2 to 10 or even more rods are embraced by a single arborization which represents one fiber of the optic nerve, Fig. 4. On the other hand each cone has a nerve fiber belonging exclusively to it. This will be referred to later on. At or near the periphery of the retina the cones are few in number and the mosaic pattern is made up of a larger disk surrounded

by many rows of smaller disks; as we near that portion of the retina corresponding to the *visual axis* of the eye the cones become more numerous and the rod less until only cones are found. The ends of the rods are in contact with six sided cells called *pigment cells* which are filled with fine granules and have a net work of fine *spindle shaped bodies* which push forward under the action of light between the ends of the rods as far as the cones. The spaces between the rods and cones and pigment cells

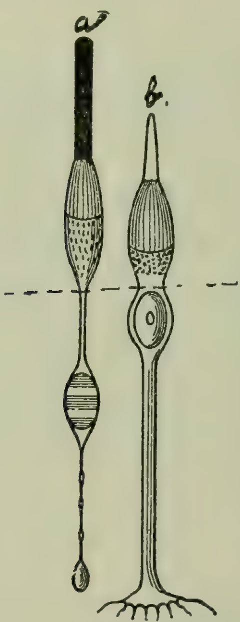


Fig. 4.—Schematic representation of rods and cones.

is filled with a fluid which contains a photochemical substance very sensitive to the action of light known as the *visual purple*.

In line with the visual axis at the posterior pole of the eye is situated an area of the retina in which vision is most distinct called the *macula*. This area is about 2–2.5 mm. in diameter. Here the rods are found in much less number until in a small pit at the center of the macular called the *fovea* only cones are present. The cones in the fovea differ from those found in other parts of the retina in that they are long, very

narrow cylinders closely massed together apparently to get as many as possible in a small space. Thus an image projected upon the fovea will cover many more cones than upon other areas of the *fundus,* Fig. 5. Microscopical measurements of the thickness of the cones in the foveal region finds they vary from 0.0015 mm. to 0.0054 mm. in diameter. The ability to distinguish two points depend upon the diameter of the cones in the center of exact vision. To be able to perceive two points as distinct and separate they must fall upon cones which are separated by at least one resting cone.

Fig. 5.—The fundus or background of the eye.

Distinct vision is found only in the macular area, a rounded patch about 2 mm. across which subtends in the human eye an angle of about 5 minutes in the field of vision which is the *visual angle* of the macula. Critical vision is to be found only in the fovea which occupies an angle in the field of vision of less than 1 minute which is the visual angle of the fovea. In a schematic eye calculated by Listing a visual angle of 1 minute corresponds on the retina to a distance of 0.00438 mm. or about the average diameter of a cone.

Outside of the macular region we obtain a general impression

of the form and color of objects over the whole of the retinal field and as a matter of fact in reading ordinary print we only see words of about four letters at a time and it is by rapid movements of the eye in various directions that gives the idea of seeing continuously.

This brings us to the muscles which control the movements of the eyeballs and by which the visual axes may be directed to any point in the field of regard. These are six in number for each eye and by reason of their attachment on the eyeball turn it up, down, in, out and if working in conjunction with each other orient the eye in any of the intermediate positions, Fig. 6.

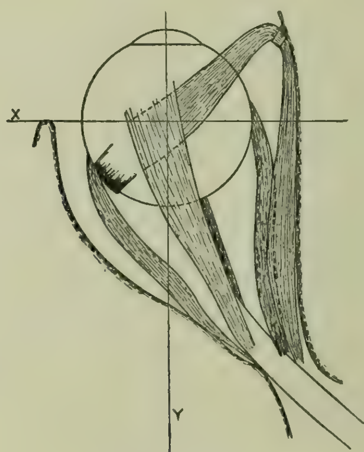


Fig. 6.—Extrinsic muscles of eye.

The discussion so far has shown that we have in the normal eye an apparatus which allows the entrance of impinging rays of light, extraneous rays are largely cut out by a diaphragm, which acts reflexly depending upon the intensity of the light; a lens brings the rays of light to a focus up a highly organized nervous structure thus completing the physical phase of the visual act.

PHYSIOLOGICAL PHASE.

The highly organized nervous structure or retina transforms the radiant energy waves into nerve stimuli constituting the physiological phase.

The fibers of the optic nerve are as insensible to light as the fibers of other nerve trunks, as is demonstrated by the experiment first performed by Mariotte who discovered the *blind spot* in the eye. Purkinje demonstrated that the light perceiving portion of the eye must lie behind the nerve fiber layer of the retina from the fact that we can perceive the shadow of the retinal vessels in our own eyes. Exact physiological measurements

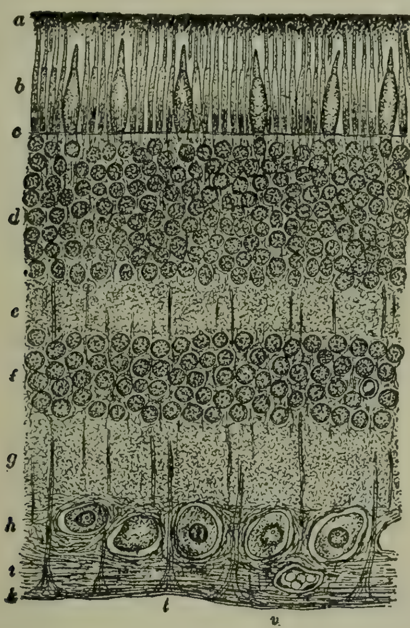


Fig. 7.—Microphotograph of cross section of retina, showing (*a*) pigment cell layer, (*b*) rod and cone layer.

has shown that the distance between the vessels and the light perceiving layer must be from 0.17 to 0.33 mm. which distance takes us to the rod and cone layer. Hence it follows with great probability that the latter structures, the rods and cones, are the light perceiving parts of the retina.

This in fact is substantiated by the anatomical relations of the rods and cones to the individual nerve fibers of the optic nerve.

The excitation which will effect the receptive portion of the specialized organs of sense differ materially from those capable of

stimulating the nerve fibers themselves and must be converted by the terminal organ into the adequate kind of nerve excitant. Nervous stimuli are of mechanical, electrical, thermal or chemical nature and into such character must external energy be transformed when it varies from the nervous stimuli in quantity or when it is of a different quality, such *e. g.,* as waves of sound or light.

Retinal Changes Due to Light.—When light falls upon freshly exposed retina the latter undergoes a number of changes which are objectively demonstrable. The spindle shaped pigment granules in the pigment layer migrate toward the rod and cone layer. The pigment will not move if the central nervous system is destroyed, and its reaction may take place in one eye as a conse-

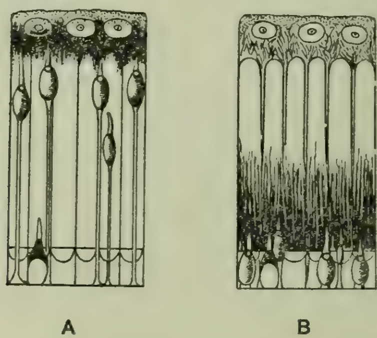


Fig. 8.—Section through the retina of a frog's eye, after Engelmannn. A, after the eye was kept for from one to two days in complete darkness; B, kept for 24 hours in the dark, then exposed for one-half hour to diffused bright daylight.

quence of light falling on the opposite retina. The cones which in darkness or dim light are near the pigment layer move inward toward the nerve fiber layer. The rods on the other hand elongate under the influence of light, their movement being opposite to the cones. The galvanometer shows the action current of the retina directed from the nerve fiber layer to the rod and cone layer undergoes a positive variation which changes upon the removal of the light stimulus.

After the eye has been kept in darkness for a time there is a marked difference in the sensitiveness of the retina to light.

This is known as dark adaptation, Fig. 9. In this state the peripheral regions of the retina are relatively more sensitive than the fovea to light of moderate intensity and to short wave-length. Adaptation to darkness is characterized by an increase in responsiveness to short waved light, and this change is mainly if not entirely, extra foveal. The perception of colored light varies in different portions of the retina, being sharpest at the fovea. Passing toward the periphery the color sense gradually diminishes. For the colors yellow, blue, red and green, yellow has the most extensive field, blue next and green the least. Most

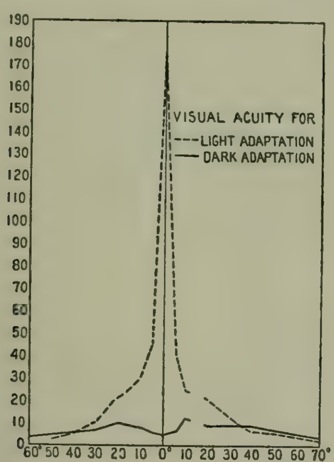


Fig. 9.—Visual acuity curves for light and dark adaptation.

authors state the extreme periphery of the retina is totally color blind.

The visual purple which is present in all parts of the retina except the fovea or yellow spot (note the exception) and is found mainly in the outer limbs of the rods fades or is decomposed when exposed to light.

The bleaching or decomposition of the visual purple depends on the intensity of the light, and while all colored light has the power of decomposing this substance, with weaker light, hours and even days, are needed to complete the action. With different colors of monochromatic light the process takes more or less time; "in yellow green the purple is altered instantaneously;

in the spectral colors, from greenish yellow to indigo, the process requires from 2 to 10 minutes; in yellow, 20 minutes; in violet and orange, 30 minutes; in ultra-violet, 45 minutes, and in red still a somewhat longer period of time." While blended light, including waves of greater and lesser refrangibility produces the

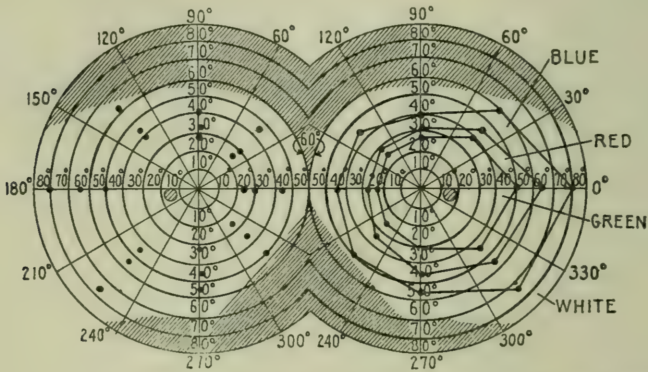


Fig. 10.—Chart for recording boundaries of color field. Chart on right shows boundaries of normal color field by Wm. McLean.

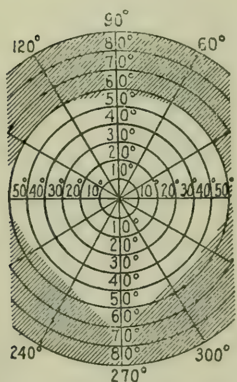


Fig. 11.—Binocular field of vision.

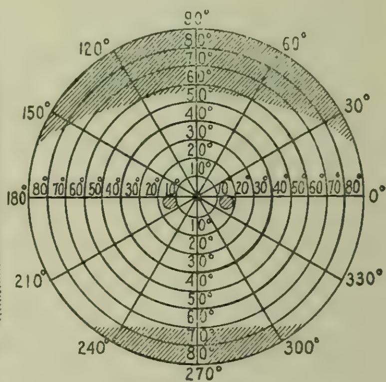


Fig. 12.—Binocular field of view.

maximum effect, each individual color of such mixture acts for itself, and only better so far as the total decomposition of the purple is concerned, when it is united with the others. The electrical response of the retina appears in the apparent absence of the visual purple, although the reaction is more intense if this

pigment be present, and it is clear that the whole effect varies in intensity with the part of the spectrum employed. Regeneration of the visual purple in the outer segments of the rods takes place rapidly in darkness or dim light, apparently being derived from a substance contained in the pigment cells known as *rhodophyllia.*

Visual Acuity.—The sensitivity curve of the eye for luminosity at ordinary intensities shows a maximum effect in the yellow and green portion of the spectrum. Dr. Louis Bell states that it is only by virtue of the high maximum point in the luminosity curve of the eye that we are able to see distinctly at all, and that if the extremes of the spectrum were highly luminous there would be no definite focal surface for which accommodation could be adjusted, the violet rays being brought to a focus in front of the retina and the red rays behind it in the emmetropic eye. It is a well known fact that the luminosity curve of the eye varies with the intensity of the light, shifting toward the green with illumination of low intensity and toward the orange and red with illumination of high intensity.

Luckiesh has determined that visual acuity, for a reading distance of 33 cm. with monochromatic light, is greatest in the yellow green of the spectrum. Thus, it would seem that the radiant energy which has the greatest decomposing action on the visual substance is productive of the greatest visual efficiency, that is, the yellow green waves.

Duplicity Theory of the Function of the Retinal Structures.—The reaction of the different areas of the retina to light stimuli in the conditions known as light and dark adaptation studied in conjunction with the difference in the histological structures between the fovea and the surrounding retinal area has given rise to a theory of the function of the rods and cones, *i. e.,* two distinct mechanisms exist. The cones are concerned only with the recognition of colors and of colorless sensations, can only act in bright light and their responsiveness is little if at all increased by resting in darkness. The rods are unaffected by colored light but are brought into play when the eye has been shielded from light, and, are the chief factors in twilight vision.

Duplicity Theory.—This theory does not account for the

activity of the cones in the peripheral portions of the retina which are not by any means functionless in either light or dark adaptation.

The difference between acute central vision and indistinct peripheral vision is marked and while central vision is far superior to peripheral in respect to the optical perfection of the image of an object and the fine perception of detail, peripheral vision is superior in the perception of movement.

Corresponding to these functional differences the eye may be considered as an organ which unites two forms of apparatus of different functional value.

The "central eye" is an elongated eye with a narrow-angle field; the possibility of a high grade of visual acuity is associated with the delicately inlaid sensory elements, and the provision of an isolated sensory path for each end element. The "peripheral eye," on the other hand, has a wide angle field and a mosaic of end elements with concentrated sensory connections, and is less adapted for keen perception of detail. The periphery, however, has an advantage over the center in the elements necessary for vision in dim light. This great difference in the conditions of acuity in the center and in the periphery of the retina is evidently connected with some anatomical peculiarity of the area in the center, and this, as has already been mentioned, is found in the isolated individual nerve connections of this part in contrast to the more concentrated ones in the periphery. The areas of discrete sensation in the retina, therefore, differ according to their position, and in the elaboration of this idea the gradual diminution in number of the cones from the center to the periphery is significant. In the center of the retina cones alone occur, but as we pass outwards rows of one, two, three or four rods are interposed between the cones which themselves become thicker. The correspondence appears a simple one, but a more careful comparison will show that the diminution in acuity is proportionately greater than the reduction in the cones.

In support of the duplicity theory various facts of physiological optics are given:

The Colorless Interval.—If a feeble spectrum be observed by

an eye well adapted for darkness, colorless light will first be seen, and only as the intensity is increased will color be perceived.

Purkinje's Phenomenon.—If selected matched red and blue objects are placed together so that in daylight the red appears lighter than the blue, and the illumination be gradually reduced, as adaptation increases and the illumination diminishes, the red object will grow darker and even appear black, while, on the contrary, the blue will grow lighter and more white.

The variation of the maximum point of the luminosity curve for different intensities of light was mentioned above, for the dark adapted eye the maximum point is found to be in the green. (533 $\mu\mu$.) Investigations have shown a correspondence between the curve of scotopic or dark luminosity and that obtained by the bleaching effect of light upon the visual purple. This correspondence in the curves can not be accidental and the upholders of the duplicity theory see in the visual purple and the structures which contain it, the rods, the elements and the visual material for vision in the dusk. The view of the duplicity theory that the sensation of white (and grey) in the light adapted eye is brought about by the color-perceiving cone elements, and in the dark adapted eye by the rods and the visual purple, is freely considered to be very doubtful. It must not be forgotten that the facts given above have hardly any analogy in the physiology of the other senses. The supporters of the duplicity theory consider total color-blindness as a condition of the eye in which sensation occurs entirely through the activity of the retinal rods, which contain the visual purple; the cones being absent or functionless. The peculiar distribution of luminosity in the spectrum of the totally color-blind appears to favor this view, the complete absence of color vision and the photophobia also agree with it. The functional activity of the rods alone is favored by the condition of visual acuity, which differs from that of color seeing people, in that it increases in a different manner when the light is increased, and does not show that sharp bend upwards, which in the normal can be referred to the visual power of the cones.

In the totally color blind the existence of a central scotoma for color such as is found in the dark adapted eye with feeble light would be especially significant, for, a defect must be present at

the point of central vision to correspond with the dark adapted eye. In many cases, though not in all, such scotoma can be found.

The idea that the cones have a lower sensibility in total color-blindness is a very attractive one as their complete absence does not appear proven by the observations which we have been considering. The defective vision, the absence of color sensation, and the other symptoms can be considered, without any straining, as due to a severe restriction of the function of the cones along with an increase in that of the rods.

Mechanical Theory of Vision.—It has been assumed by some observers that the light waves act mechanically, the wave movements setting into vibration portions of the external segments of the rods and cones, and that this mechanical movement forms the direct excitant of the nerve impulses. The general view at the present time, however, is that the process is photochemical; that is, the impact of the ether waves sets up chemical changes in the rods or cones which in turn gives rise to nerve impulses that are transmitted to the brain.

Color Vision.—This brings us to the physiology of the perception of colored light and the theories advanced to account for the peculiar condition of vision found in about one out of every twenty-five males known as color-blindness. There are many theories advanced, the chief among which are those of Young-Helmholtz, Hering, and Edridge-Green.

The Young-Helmholtz Theory.—This theory (first proposed by Thomas Young in 1807, and subsequently modified by Helmholtz) assumes that the terminal fibrils of the retina are arranged in three distinct sets for the reception of the three primary colors—red, green, and violet. These groups correspond to the three colors, and acting simultaneously induce the sensation of white. Red light entering the eye affects to the greatest extent the group of filaments known as the red sensitive elements, and also affects the others to a slight degree. In like manner green and violet are perceived by their corresponding sensitive elements. The absence or imperfect development of the retinal area set aside for one of these primary colors will cause this color to be seen as if composed of the two remaining colors, thus giving rise to color blindness corresponding to the deficient color elements.

Fig. 13 shows the manner in which the quantitative stimulation of the individual fibers by yellow or blue is to be appreciated on this hypothesis.

The conclusions drawn from the laws of light mixture have in recent times found a technical application of this theory in the Lumieré color photography. In front of a sensitive plate is a screen formed of minute grains of starch colored red, green and violet. The variously colored light passes through the starch grains in a selective manner with respect to quantity and quality, according to the valency curves and makes its impression on the bromo silver plate. The plate is then developed as a diapositive, and will filter light in the same manner,

Fig. 13.—Valency curves of the three components of the color sense.

only allowing the original colors to pass; thus a very fine photograph in natural colors can be obtained.

Hering Theory of Color Vision.—This theory assumes the existence of three separate visual substances in the retina. Each of these substances is decomposed by the action of light and is renewed when the eye is permitted to rest in the dark. Both the decomposition and the renewal of the visual substances result in the production of color sensation.

The Hering visual substances are divided into three sets of two each, *i. e.*, (1) white-black substance; (2) red-green substance; (3) blue-yellow substance.

When the black-white substance is decomposed the sensation of white is produced. When this substance is renewed the sensation of darkness results.

When the red-green substance is decomposed the sensation of red is produced, and when it is renewed the sensation of green results.

When the yellow-blue substance is decomposed the sensation of yellow is produced; when it is renewed the sensation of blue results.

Red light produces the sensation of red by decomposing the red-green substance. Orange light produces the sensation of orange by decomposing both the red-green and the yellow-blue substances. Yellow light produces a sensation of yellow by decomposing the yellow-blue substance, the red-green being then in equilibrium. Green light produces the sensa-

tion of green by the renewal of the red-green substance, the yellow-blue being now in equilibrium. Blue light produces the sensation of blue by the renewal of the yellow-blue substance. Violet light does the same, though to a less degree.

This objection can be taken to Hering's theory, that in the black-white form of sensation there is no different point which cannot be compared to white or to black, as is the case with the red-green or the blue-yellow; there is also a doubtful element in the hypothesis in that it is not only the process of dissimilation that produces a stimulus, but perception may also be due to assimilation. The well known phenomena of contrasts are well explained by this hypothesis; *i. e.,* after steadily fixing a colored pigment, and then looking at a colorless surface, the contrast color appears. Just as this "successive contrast" is well explained, so also is the "simultaneous contrast." In this condition, which is shown in the appearance of colored fringes, the dissimilation of a definite visual substance will induce the assimilation of the same substance in the adjoining parts, and thus the appearance of the complimentary color. Color perception in peripheral vision is also in favor of Hering's theory.

The Edridge-Green Theory.—The latest and probably most comprehensive theory is that of Edridge-Green in which he accounts not only for vision and color vision, but for the transformation of radiant energy into nerve stimuli.

Edridge-Green conceives that the cones are the terminal perceptive visual organs. The rods are not perceptive elements, but are concerned with the formation and distribution of the visual purple. Vision takes place by stimulation of the cones through the photo-chemical decomposition by light of the liquid surrounding them which is sensitized by the visual purple.

The character of the stimulus differs according to the wave-length of the light causing it. In the excitation itself we have the physiological basis of the sensation of light, and in the quality or wave-length of the excitation the physiological basis for the sensation of color.

There are three objections made to the Edridge-Green theory that the visual purple is the visual substance.

(1) The chief objection is that it is not present in the cones. The author maintains this is a necessary requisite to the theory.

(2) That animals such as frogs naturally possessing the pigment continue to see after their visual purple has been absolutely bleached by prolonged exposure to strong light. The author contends that the retinas which were bleached by sunlight and with which the frogs were still able to see, in reality contain sufficient visual purple or its decomposition products for vision, but not enough for external recognition.

(3) That the visual purple is entirely wanting in some animals which see very well. This is based upon erroneous observations, and in case of certain animals supposed to have no visual purple or no rods, subsequent observers have found both; for instance, the butterfly, bat and tortoise. Even if there were no visual purple the argument fails because there might be some other means of stimulating the cones.

The following are a number of arguments given in support of the Edridge-Green theory:

(1) Visual Acuity: This corresponds roughly to the distribution of the cones. Though the rods are much more numerous in the periphery of the retina visual acuity is very much less with this part.

(2) The relation between the foveal and the para-foveal regions. As there are no rods in the fovea, if the rods and cones were percipient elements of a different character there ought to be a qualitative difference between these regions. The Purkinje phenomenon, *i. e.*, the alteration of optical white equations by the state of dark adaptation, the colorless interval for spectral lights of increasing intensity, the different phases of the after-image, all exist, not only in the para-foveal, but also, only gradually diminished, in the foveal region.

The misstatement has been made that the Purkinje phenomenon (the fact that if an equally bright red and blue be viewed by a light of considerably diminished intensity the blue appears much brighter than the red) is not found in the foveal region. One can easily ascertain for himself that the Purkinje phenomenon is found in the fovea by taking a red and a blue into a dimly-lighted room, the red being brighter than the blue in ordinary conditions, he will find that the blue will appear brighter than the red with direct vision, and still more so with indirect vision, he will find

that in no position of the eye can he see the red brighter than the blue.

(3) Chemical Analogy: The visual purple gives a curve which is similar to that of many other photo-chemical substances. With such substances a different curve is obtained with weak light from that observed with light of greater intensity and it is reasonable to suppose that the visual purple which is formed by the pigment cells under the influence of a bright light would be somewhat different in character from that which is formed in darkness.

(4) It is a misstatement that the periphery of the retina is color-blind. It is entirely a matter of the intensity of the light employed. Bright spectral colors can be seen at the extreme periphery of vision. All lights when sufficiently small and feeble appear white even at the fovea.

(5) The varying sensibility of the fovea is explained on the theory that when there is visual purple in the fovea this is the most sensitive portion of the retina; when there is none there it is blind. It also shows conclusively that the fovea is sensitized from the periphery.

(6) Disappearance of lights falling upon the fovea shows that when the visual purple in this area is used up and not renewed the latter is blind.

(7) Currents seen in the field of vision are not due to the circulation but are formed by the flow of sensitized liquid.

(8) The movement of positive after images by a jerk of the head shows that the photo-chemical stimulus is external to the cones and can be moved.

(9) Dark adaptation is easily explained by assuming that the liquid round the cones becomes more sensitive through a greater percentage of visual purple being poured into it. In light adaptation the anatomical arrangement is such as to prevent as far as possible the decomposition of the visual purple.

The ability of the normal eye to distinguish the form of an object depends upon (1) the size of the image received upon the retina; (2) the amount of light reflected from it; (3) the contrast with the background. The results obtained from the examination of a great many individuals with good sight have shown that with the average eye the form of an object can be recog-

nized if the angle subtended by it at the retina equals five minutes and parts of the object, such as a letter, which subtend a 5-minute angle, are wide enough to subtend a 1-minute angle.

The amount of light reflected from an object must be sufficient to act upon the photo-chemical visual substance and cause stimulation of the nerve endings. The coefficient of reflection between an object viewed and the background must differ sufficiently to make a contrast; otherwise the object will be invisible.

Summary of Physiological Phases of Vision.—A light wave starts on its journey through the ether from some luminous object or reflected from some surface which is its source. The various rays parallel, divergent or convergent, as the case may be, are brought to a focus upon the background of the eye. The first step towards its becoming a visual impulse is taken when it decomposes the photo-chemical substance of the retina, thus setting up vibrations in the cones of this membrane.

The excitation received by the retinal substance and structures is conveyed by fibers of the optic nerve back to centers at the base of the brain, and either directly or by new relays of fibers to the visual centers of the brain. Definite portions of the retina are related to equally definite portions of the visual center of the brain which first receive the projected retinal excitations. The result in the brain centers first receiving the impulses is a visual sensation or percept. Up to this time, however, no idea of the object looked at is obtained. In order that this shall come to pass the brain excitation which has been brought about must be transmitted to another region of the brain surface; in other words, from a simple perception center to a memory center where it is recognized.

There are several factors which interfere with the adequate carrying out of the physical phase of vision, such as far-sightedness, near-sightedness and astigmatism. However, as we are considering a normal or emmetropic eye, this will not be gone into.

The sensitiveness of the visual apparatus to radiant energy is a most interesting and absorbing study, but time and space will not allow of more than a mere mention.

Of all the energy emanating from a light source, such as an incandescent lamp, only 5 per cent. is perceived by the eye as light, as is graphically represented by slide projected on the screen. This small portion of the radiant energy of an incandescent body appreciated by the eye is known as the visible spectrum, and is bounded by wave-lengths 760 $\mu\mu$, recognized as deepest red, and wave-length about 400 $\mu\mu$, seen as deepest violet. The action upon the eye of wave-lengths longer than 760 $\mu\mu$, known as infra-red rays, is still, to a certain extent, a moot question, but they are considered to be a factor in producing opacities of the lens. The wave-lengths shorter than 400 $\mu\mu$ are designated as ultra-violet rays, and are known to produce intense inflammatory reactions of the outer coats of an unprotected eye, when exposed to intense light, containing a high percentage of these radiations.

The various transparent media of the eye, the cornea, aqueous humor, lens and vitreous, have selective absorption characteristics for these rays, which protect the retina under ordinary conditions. As infra-red and ultra-violet radiations are of no known aid in the visual act, it is a wise precaution to shield the eyes from them by means of protective glasses, which have selective absorption action for these particular rays, provided, however, that the glass does not cut down the amount of light gaining entrance into the eye to an extent that will interfere with the proper decomposition of the visual purple. The selective absorption of some of these glasses is shown.

The subject of after images, color contrasts, simultaneous contrasts, complementary colors, recurrent vision, binocular vision and spatial vision, cannot be gone into in the time and space allotted.

PSYCHICAL PHASE.

The psychical phase of vision will be briefly mentioned, and is largely quoted from Lohmann:

While color perception by the eye is induced from a light stimulus and the essential conditions are generally provided by physiological stimuli, the perception of color itself is a psychic phenomenon. With the color impression called forth by the stimulus are associated those representations called memory-colors, and

thus the same percept is insured even though surrounding conditions vary. Cloths, whose color has been recognized by day, are viewed by artificial light, when to a really unprejudiced eye, they present quite another appearance, but seem to be seen in their "correct" colors in the artificial light; we also speak of white snow, even when the dusk of twilight has changed it to grey.

The psychic element in vision is very obvious in the following example, which Helmholtz gives in his "Physiological Optics." Imagine oneself to be in a brightly lighted room; impressions are then accompanied by powerful sensations. We find ourselves at dusk in the same room, seeing only the lighter objects, and these indistinctly. Everything which we notice so fuses with our memory-pictures that we can readily find objects looked for. Even in absolute darkness, we can find our way in the room by virtue of the memory of previous visual impressions. This example of the reduction of the presentation image "by an ever increasing elimination of its sense elements to a pure re-presentation image," shows us the intimate connection between the purely sensory and the purely psychic in our concepts and ideas.

In fact, our concepts are not induced merely by the visual impressions of the moment, but necessitate the addition to these of re-presentations of sensations; these we adequately term "factors of experience." It is not always possible to separate the pure sensation from the factor of experience.

When I look at a portrait drawn so that the eyes look at me, and then walk about the room, I have the impression that the portrait is always gazing at me. This fixed gaze of the portrait, an easily proved empiricism, is not induced by reflexion, but is the result of an overwhelming sensory impression.

The analysis of the fact that the factor of experience is so important in vision, is by no means simple; it presents a difficult problem to the psychologist. A relatively simple explanation is provided by the hypothesis that the psycho-physical substance as a result of its activity suffers changes, and that residual sensations previously left behind are met with and have a modifying action on a new sense impression.

To produce a picture from the individual sensory stimuli of

the retina, we must have the component parts built up into a complex percept. Witasek talks of a "process of production," and his meaning becomes clear when we consider how the same form of stimulus in the same state of the eye can produce different perceptions.

Importance of Vision.—In examining the importance of vision, we must take into account the relation of our eye to objects seen, and also the relation of the objects to us. We have to answer two questions: 1. What does sight convey to us regarding external objects? 2. What influence has sight on our intellectual life and comfort?

What Does Sight Convey to Us?—The first question introduces a much discussed philosophical problem, and ends in the well known question of objective existence. We either deny a correspondence between our perceptions and the actual objects, and explain all sense perceptions as subjctive phenomena, and sense delusions as not actual realities; or we admit a conformity between the world around us as we subjectively find it, and as it objectively exists.

In the latter case we speak of a "pre-established harmony" (Ehrhart), and consider that a correlation between mind and matter is shown because the power of mind is derived from the same source as are the forms of energy in the world around.

In contrast to such speculative answers to the problem of the relation between vision and the world around, Helmholtz emphasized the practical point, which appears when we consider that surrounding objects by means of our sense impressions become to us symbols which, when we have learnt to interpret rightly, make it possible for us to direct our actions so as to bring about desired results. Although the eye is extremely useful, practically, it cannot see at all distances, nor perceive all the vibrations of the ether. In the same way we have no guarantee that human intelligence might master everything which can exist or occur.

The common view of simple people that our vision says something about an object has led to an unfortunate method of expression, which appears when we speak of "red" sealing wax.

To a color-blind eye, this is not red; it is only in the case of a normal eye under ordinary conditions that the rays of light reflected from the sealing wax produce that definitely characterized sensation (red).

Influence of Sight on Intellect.—Regarding the second question, the importance of vision to our intellectual life, the view was prevalent amongst the ancients that the many distractions which our visual impressions bring us, prevented an undisturbed development of the soul. Cicero's statement that Democritus had blinded himself in order to reason more clearly would thus be easily understood. We tend, when reasoning, to shut our eyes; but their closing is only temporary against any influence which would interfere with the concentration of the mind. On the other hand, we must recognize that the "hasty glance" will, through visual impressions advance our quickness of mind, and to a certain extent is a form of mental gymnastics.

The eye is an organ which enables us not only to recognize objects in the vicinity, but also parts of the country, the sea, and the starry sky, in the far distance. Our visual impressions are closely related to perceptions of space, and recognition of time. We will readily be convinced that a spatial sensation of depth is transmitted (extent in height and breadth is conveyed by each eye separately) if we attempt to estimate the position of an object relative to ourselves by monocular vision. It must be admitted that depth is only recognized indirectly with the one eye, in contrast to the immediate and obvious estimation of the position of objects one behind the other which is gained binocularly. Impressions as to succession in time are also conveyed by our visual sense; and it might be added, more frequently by this means than by the other sense organs. For the whole field of vision forms the fundamental chord, the continuous impression, in which a movement or an alteration occurs; we see solid objects grouped together constantly, changing in their relative positions. It is thus quite obvious what a great intellectual use we make of our visual impressions, so variable in space and time.

The whole play of our imagination draws freely for material on memory pictures derived from vision, so that visual impressions are the source of a large portion of our inner life.

The true importance of vision to us will be clear if we try to imagine what would remain of our intellectual existence if all visual impressions and the memory of them, were banished. We must confess with Goethe:

"Place yourself in what state you will, you will always think of yourself as seeing."

SIMPLIFICATION OF ILLUMINATION CALCULATIONS.*

BY A. S. MCALLISTER.

As marking the transition of the science and art of illumination from the methods of the physicist to those of the engineer, no one milestone stands out more prominently than that represented by the presidential address of Dr. Clayton H. Sharp in 1907. Following his presentation of certain concepts and terminology in illuminating engineering, not only was there a change in the output rating of lamps from the indefinite and much abused candlepower to the definite and now well-understood lumen, but many improved methods were developed for solving problems in illumination. In many respects the results have been similar to the substitution of the flux method for the isolated unit pole method of solving problems in magnetism.

While from the point of view of physics there are marked differences between the concept of magnetic lines or "tubes" force and that of lines or "cones" of radiant energy, yet in their mathematical treatment the problems relating to the one are quite similar to those relating to the other.

So far as numerical results are concerned, it is absolutely safe to ignore the direction of travel and mode of propagation of the radiant energy from the source of light to the surfaces upon which this energy is absorbed. Of one relation we can be absolutely sure, namely, the total energy absorbed equals the total energy produced. When methods of calculation give results not in conformity with this relation it is safe to state that the methods are wrong either in principle or in application. Thus for checking results obtained by more laborious methods the absorption-of-light method is highly advantageous. In many instances, yes in most cases, it is permissible to abandon the more complicated methods and rely upon the simplest and absolutely correct energy-ratio method, with merely an occasional reference to some more indirect method for determining the space distribution of the illumination where this is of importance.

* Presidential address at ninth annual convention of the Illuminating Engineering Society, Washington D. C., Sept. 20-23, 1915.

Looking back over the TRANSACTIONS of the Illuminating Engineering Society since its first meeting in 1906, one cannot but be impressed by the fact that almost all of the solutions offered for problems in illumination have been based on the tacit assumption of point sources rather than surface sources. Even when dealing with plane surface sources the authors have usually treated them as made up of an infinite number of point sources arranged in one plane, and have based their solutions on the "inverse square" law and other relations developed from the fundamental point-source conception. In order to obtain results consistent with the known facts in this case, it has been necessary to assign to each infinitesimal point source in the plane certain physical characteristics not possessed by ideal point sources, such as the ability to produce light in only one hemisphere which is the fundamental attribute of an infinitesimal plane surface source.

It needs no argument to show that all calculations are immensely simplified by adopting initially the surface source conception and utilizing at once the well-known relations developed for surface sources.

Instead of determining the illumination produced by the source on a chosen plane by reference to the "inverse square" law and the integrated "candlepower," the identical value can be derived more conveniently by means of the fundamental ratio existing between the "apparent luminous density" of the source and the lumen density on the surface illuminated, which ratio depends solely upon the solid angle subtended by the source when viewed from the chosen plane.

Allow me to call attention at this point to a fact learned by us all in our school days, but mostly forgotten since then; namely, the extreme ease with which solid angular relations can be represented by straight lines and circles in planes. As a result of this fact simple circle diagrams can be utilized for solving graphically problems in solid angular relations the solutions of which become very complicated when any other method is employed.

Ignoring for the moment the physical interpretation of the change in conception from the "point" to the "surface" source allow me to mention here the significant fact that the solution of a problem when based on the one conception is identical with that

found when the other conception is employed, so that any errors which may be attributed to the one conception must likewise be urged against the other.

When dealing with surface sources it is necessary to take into consideration the fact that not all surfaces obey the so-called "cosine law" of emission in accordance with which a surface would appear uniformly bright when viewed from all possible locations. However, it is equally necessary to take into consideration the fact that the candlepower from a so-called point source or the "apparent candlepower per unit area" from a surface source is not uniform in all directions in space. The fact of the matter is that all practical sources omit light in such a way as to appear non-uniform in brightness over the surface when viewed from any one locality, and any one point on the surface apparently varies in brightness when viewed from different locations in space. It is impossible so to express the brightness that its value will not be subjected to the changes here referred to.

If the surface were ideally perfect in its emission, its brightness would be everywhere equal and uniform, and its apparent candlepower would vary with the cosine of the angle of deviation of the surface from normal to the line of vision; that is the surface would obey Lambert's "cosine law of emission." A surface which is not ideally perfect in emission can be compared directly with one which follows the cosine law of emission irrespective of the units in which the outputs or appearances are expressed.

For convenience in calculation and purpose of comparison, it is advantageous to express the outputs in terms of the lumens, and the output density in terms of the lumens per unit area. It is equally as convenient and logical to express the appearance in terms of the luminous output density, selecting for the unit the appearance of a surface emitting in accordance with Lambert's cosine law. For this unit of appearance there has happily been suggested the term "lambert," which is applied to the appearance of a surface emitting one lumen per square centimeter in accordance with Lambert's cosine law of distribution and is equivalent in appearance to that of a perfect matt surface of 100 per cent. reflecting power illuminated with a density of one lumen per square centimeter.

Although the introduction of the lambert brightness unit is of recent date, it is noteworthy that its exact physical definition was accurately presented before this society eight years ago in the presidential address of Dr. Sharp, who stated therein that "the brightness of a diffusely reflecting or transmitting surface is proportional to the luminous flux which it emits per unit of area."

In view of the fact that the lambert unit is based on the surface source conception, this method of expressing the brightness (that is, the appearance to the eye) seems to me to be fundamentally much more logical than the more common method involving a reference to the point source conception. It is impossible to derive an expression of brightness which does not in some way—either directly or indirectly—involve the luminous output and the surface area. That is to say, when the expression of brightness includes a reference to the point source conception, it is evident at once that there have been assigned to each infinitesimal point source physical characteristics possessed exclusively by a surface source. Simplicity in both conception and mathematical analysis dictate the reference of all brightness expressions directly rather than indirectly to surface sources and not to point sources.

Problems relating to both the output and the appearance of practical lighting sources are greatly simplified when use is made of the real surface source conception rather than the fictitious point source conception.

Independent in every respect of the units employed in expressing the output and the appearance of a surface source, it is essential to recognize the fact that only in the case of emission in accordance with Lambert's cosine law is either the output density on the appearance uniform over the surface. For simplicity in calculation it is advantageous to assign such values to these variables that the calculations will give results in practical accord with the actual facts. The mean value of the output density can evidently be found by dividing the total output by the total area of the emitting surface; this value is identical with the mean effective value of the "appearance" or "brightness" of the same source.

For all practical purposes the use of the mean effective value (in space) of the brightness introduces errors no greater than

those caused by substituting the mean effective value (in time) of an alternating current for its cyclically varying value. That is to say, problems in illumination from surface sources—and practically all sources are surfaces—are simplified by substituting the mean effective value of the output density and appearance for the actual values with their variations in space, in exactly the same manner and to the same extent as equivalent problems in alternating current phenomena are simplified by substituting the mean effective value of the alternating current for the actual values with their variations in time.

Let us carry the physical analogies somewhat further. The substitution of the lumen conception for the candlepower conception has simplified illumination calculations just as the substitution of the magnetic flux conception for the isolated magnetic pole conception has simplified magnetic calculations. Moreover, the use of the surface source conception rather than the point source conception permits of the introduction of graphical methods of solving problems in illumination equally as accurate and convenient as the simplified circle diagrams now universally employed in solving problems relating to the general alternating-current transformer.

To persons familiar with the time-honored laborious calculating methods of the electrophysicist and with the short-cut but equally accurate methods of the present-day electrical engineer, no arguments need be presented in favor of the simplified methods of solving problems in illumination other than the analogies just outlined.

REPORT OF COMMITTEE ON PRESIDENT'S ADDRESS.*

The committee appointed to report on the presidential address of Dr. A. S. McAllister, on "Simplification of Illumination Calculations," has to express its admiration for the lucid and convincing expression of the views therein contained.

The underlying thought in the address is that illumination calculations can be greatly simplified by discarding the usual method of determining the illumination produced by the source on a chosen plane by reference to the "inverse square" law and the integrated "candlepower," and using the fundamental ratio existing between the "apparent luminous density" of the source and the lumen density on the surface illuminated, which ratio depends solely upon the solid angle subtended by the source when viewed from the chosen plane. The use of the surface-source conception rather than the point-source conception permits of the introduction of simple-graphical methods for solving problems in illumination.

The committee concurs with the views expressed in the address and believes that the application of the method therein outlined will assist materially in the simplification of illumination calculations.

Respectfully submitted,

C. H. Sharp,
E. P. Hyde,
P. S. Millar,
L. B. Marks, *Chairman.*

* Presented at the ninth annual convention of the Illuminating Engineering Society Washington, D. C., Sept. 20-23, 1915.

A FLUX METHOD OF OBTAINING AVERAGE ILLUMINATION.*

BY F. A. BENFORD, JR., AND H. E. MAHAN.

Synopsis: This method applies particularly to the calculation of illumination on the floor or working plane of a large room or shop. The basis of the method is the rating of lighting units by the percentages of flux in the three zones 0° to 30°, 30° to 60°, and 60° to 90°. An index in the form of an equilateral triangle is provided. Given the flux distribution of any unit the index indicates a standard flux distribution of similar percentages in the three zones. A number of these standard distributions have been solved and made up in the form of charts. By an inspection of the proper chart the per cent. of the downward flux that falls within any rectangle is readily found. By adding these percentages for the different units of an installation, multiplying by the total downward flux of one unit and dividing by 100 times the floor area the average direct illumination is obtained.

The location of outlets and specifications for lighting equipment have, in the past, followed, in most cases, rather empirical rules. Those responsible for the lighting of buildings had very little knowledge of the fundamental principles governing lighting, and hence followed the precedents and custom that had grown up and which were based on architectural or structural exigencies.

While the authors do not contend that structural conditions should be ignored, they do feel that more consideration should be given to the proper quantity and distribution of light than is usually accorded them, and that questions relating to these items should enter as factors in determining the most advantageous position of outlets and sizes of units.

Feeling the need for a more rational method for checking illumination designs and arriving at a reasonably accurate estimate of the average illumination, the illuminating engineering laboratory of the General Electric Co. has adopted the plan described in this paper.

The designer of a lighting installation after studying the requirements of his problem decides on a suitable type of unit and the required intensity. He is guided thus far by consideration of glare, color, power required, artistic and structural details, etc., and arrives at a layout which satisfies these conditions.

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

Before passing on the final plans, however, he wishes to check his completed design and determine whether or not the required quantity of flux is being delivered on the working plane to provide the desired illumination intensity.

To the best of the authors' knowledge there are four methods in use at the present time by which the average illumination of a lighting installation may be calculated. Each has some peculiar advantage, but none possess all the qualifications desired for this class of work. These various methods are:

Average Effective Angle Method.—The light within some fixed angle from the axis of the unit is assumed to be totally effective, the remainder being wholly lost. A variation of this is to consider a certain per cent. of the light from a given type of unit to be useful, and changing this figure according as the walls and ceiling are light, medium or dark in color. Usually in using this method no account is taken of the size of the room, the spacing of units or the height at which they are hung. The basis of the method is the supposition that the units will be hung low in a small room and high in a large room, there being a fixed relation between height and area to be illuminated. But as the services of the illuminating engineer are often asked for because of some peculiarity or difficulty in the proposed installation, it is at once evident that this method is of small use.

Högner's Method.—Starting with the unit as a center, the angular dimensions of the rooms are laid out. A table of constants is provided and by multiplying the constants by the intensities of the source at 10° intervals until the boundaries of the room are reached, a figure for average illumination is ascertained. This method contains the possibilities of a great deal of development, but in the form with which the authors are familiar the method is not elastic enough to meet all the various requirements. The labor involved is an objection as is the probability of error in handling the numerous decimal constants.

Illumination Curve Method.—The floor area is covered with a network of illumination lines. The average illumination is found by multiplying the illumination at a series of points by proper area factors, adding, and then dividing the sum by the area of the room. Considerable experience is required to place the illumi-

nation lines in the best position, and a large amount of labor is required for the various calculations. The results are ordinarily very accurate, and have the great advantage of giving detailed information about the illumination. If the lamps are irregular in heights or spacing, the method practically fails on account of the time taken for calculations.

Lumen Chart.—A lumen chart devised and used in this laboratory gives a reasonably quick and very accurate answer to problems in average illumination. The great objection to this method is that the chart is a highly specialized device and it requires the use of a draughting board.

In the above review the better methods are seen to be either too long or too complicated and the quickest method is inaccurate. The combination of quickness and accuracy in the same method naturally presents difficulties, but most of these difficulties have been overcome and a method arrived at that is nearly as quick and simple as the first method, and exceeds all of the above methods except the fourth in accuracy.

PRINCIPLES OF SOLID ANGLE FLUX CHARTS.

Several new departures have been made in the development of these charts. First among these is the complete substitution of lumens for candles, and second, a series of prototype or standard distributions of flux have been made and substituted for the actual flux distributions of the multitude of characteristic curves in the laboratory files. The number of conditions that had to be considered and taken care of were six in number: 1, character of distribution of flux from unit; 2, quantity of flux; 3, height of suspension; 4, length of area to be illuminated; 5, width of area to be illuminated; 6, location of unit with respect to boundaries of area.

These charts apply only to symmetrical units and rectangular areas. The hemispherical flux of the unit is regarded as 100 per cent. divided into three thirty-degree zones, 0°-30°, 30°-60° and 60°-90°. An equilateral triangle is used to index and classify both the photometric distribution curves and the solid angle flux charts. The sum of the distances from any point within an equilateral triangle to the three sides is a constant for that triangle. Making this constant 100 per cent., the length of the

three lines to the sides may then represent the percentages of flux in three zones, thus giving every flux distribution a definite point in the index triangle.

The triangle is divided into 166 hexagons, some of which are not complete, see Fig. 1, and the central point of each is taken as a "standard" flux distribution and an arbitrary number assigned it. The total flux up to 30°, 60°, and 90° for each standard curve was plotted and a smooth curve drawn through these points furnished the data necessary to find the candle intensity

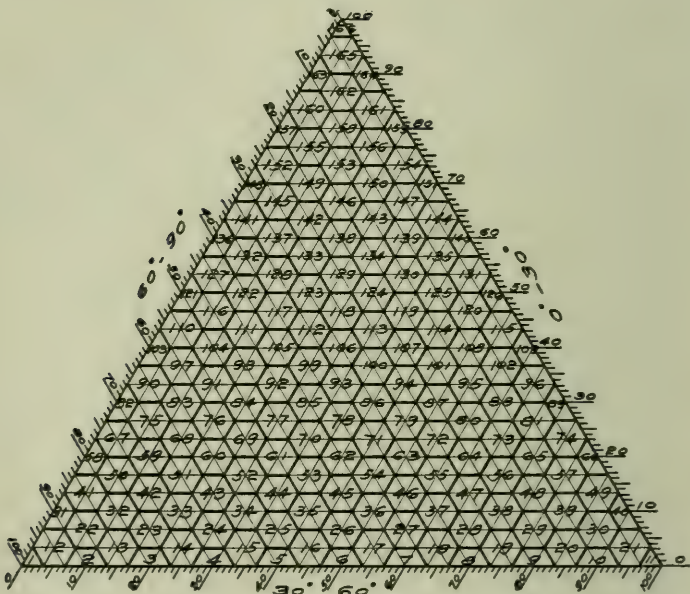


Fig. 1.—Index triangle. Solid angle flux charts.

at the various angles, as shown in the upper left hand corner of Fig. 2. These distribution curves are not essential parts of the method, but are given with each flux chart as a supplement to the index.

These standard flux curves were solved to find the flux incident upon various rectangles and the results plotted on the charts. The charts were then provided with several scales of lengths and widths, so that a direct reading scale may be found for almost any lamp height and for any size area.

The section of the index triangle in which the common distributions fall is bounded roughly by lines drawn from hexagon 13 to 21, from 21 to 115 and from 115 back to 13. Sixty-one

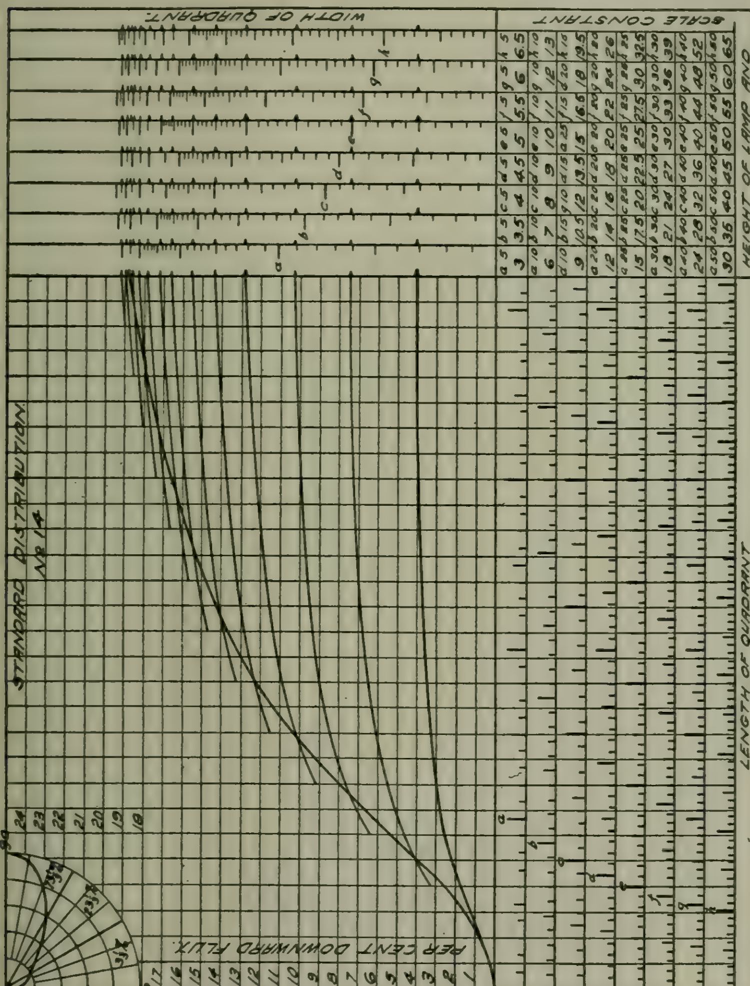


Fig. 2.—Standard distribution chart No. 14.

standard flux distributions are embraced in this area, and they make up the laboratory set of charts. Examples of three extreme distributions are shown in Fig. 2, Fig. 3, and Fig. 4.

APPLICATION.

Some of the details of the method are best brought out by an

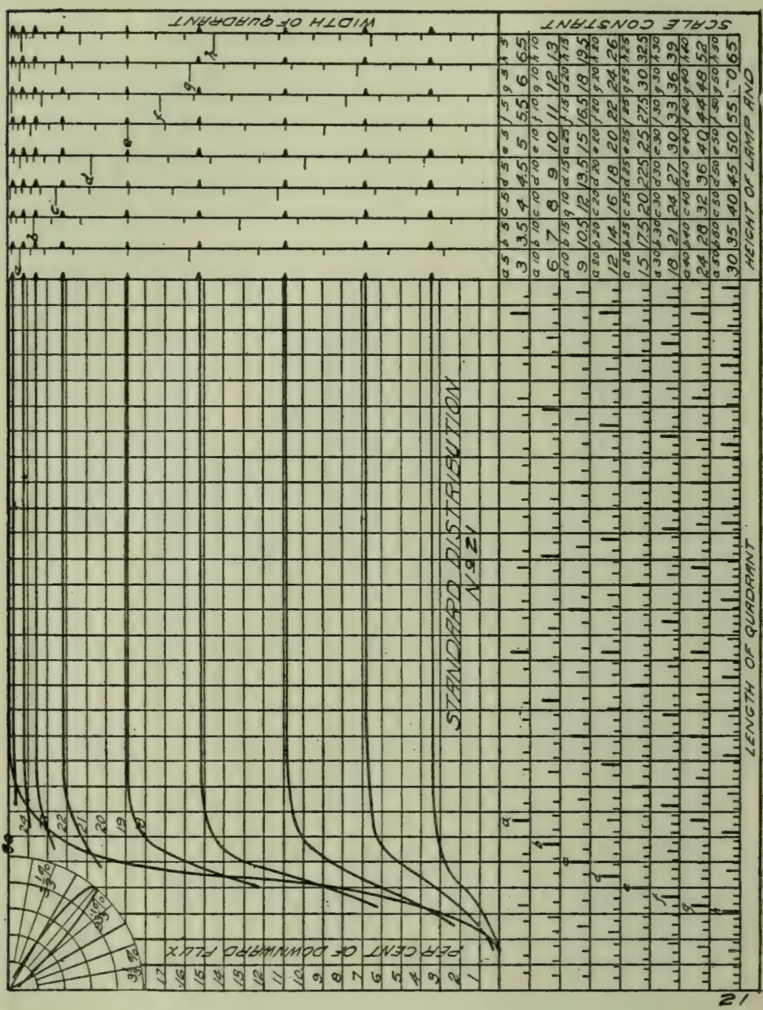


Fig. 3.—Standard distribution chart No. 2. (Copyrighted.)

application to an actual installation, such as is described below. The units were arranged as shown in Fig. 5, and their photometric characteristics are given in Fig. 6.

The first step is to determine the index number of the unit.

The flux distribution, as obtained from the photometric curve, is 23.2 per cent. in zone 0° to 30°, 59.2 per cent. in zone 30° to 60°

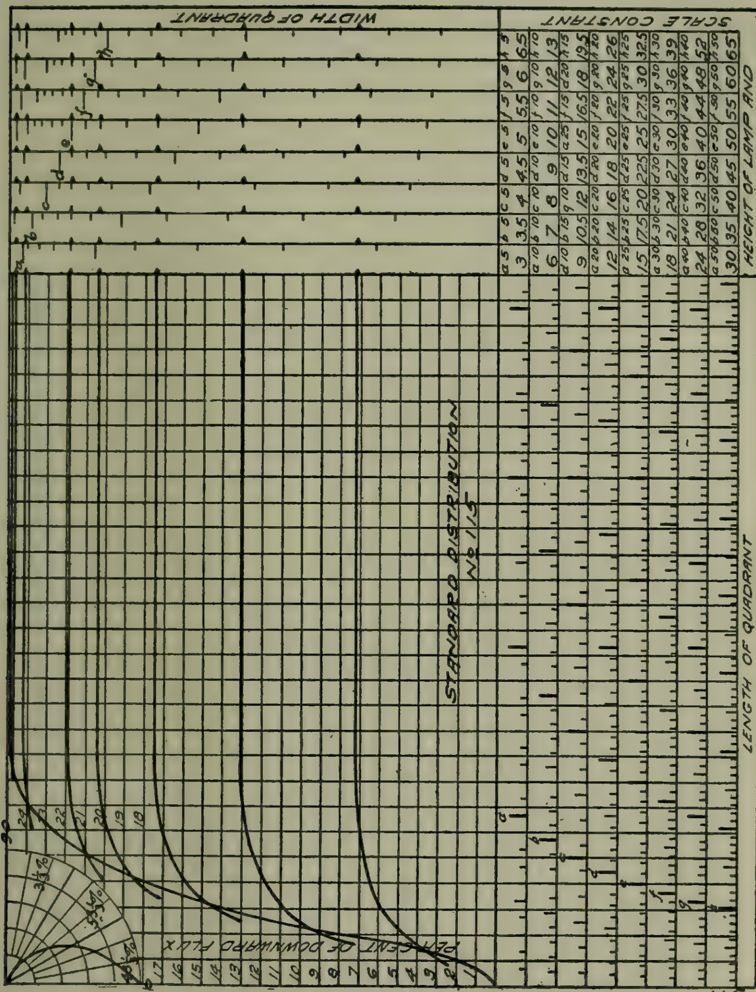


Fig. 4.—Standard distribution chart No. 115. (Copyrighted.)

and 17.6 per cent. in zone 60° to 90°. This distribution falls in the upper part of hexagon 64 in the index triangle, Fig. 1. The flux chart for this area is No. 64, shown in Fig. 7, in which the flux percentages for the three zones are 20, 60 and 20 per cent.

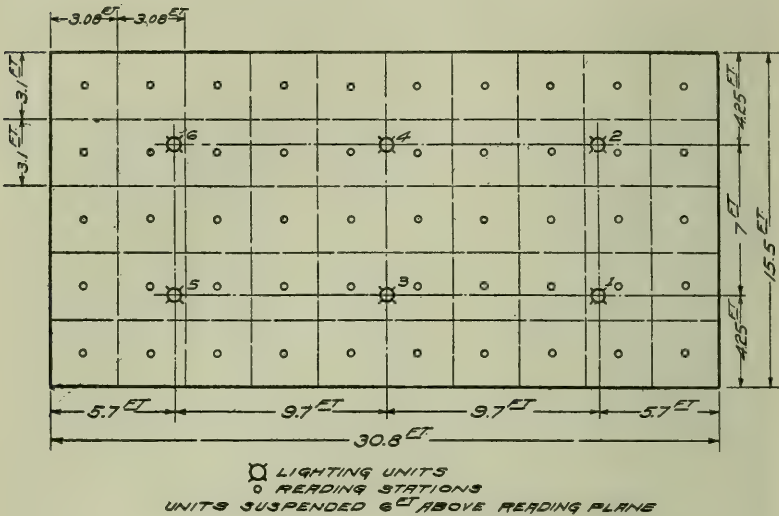
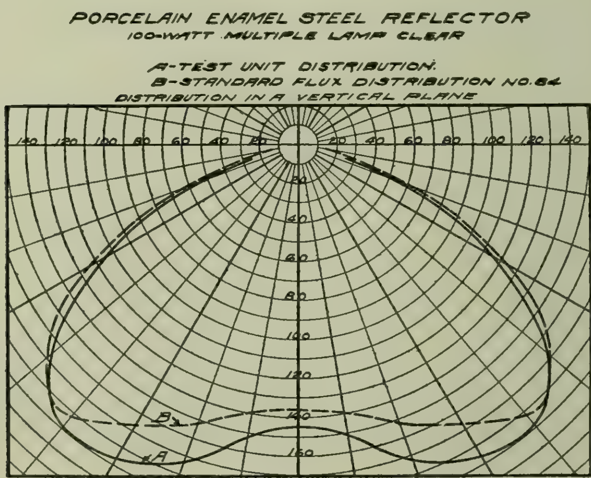


Fig. 5.—Plan of test room.



	TEST UNIT		STD. FLUX DIST. NO. 64
DEGREES.	LUMENS.	PER CENT.	PER CENT.
0 TO 30	148	23.2	20.0
30 TO 60	378	59.2	60.0
60 TO 90	112	17.6	20.0

Fig. 6.—Distribution curve of test unit.

The actual distribution and the standard distribution are given so that a comparison may be made. The standard curve is corrected to give the same total flux as the actual curve. It might

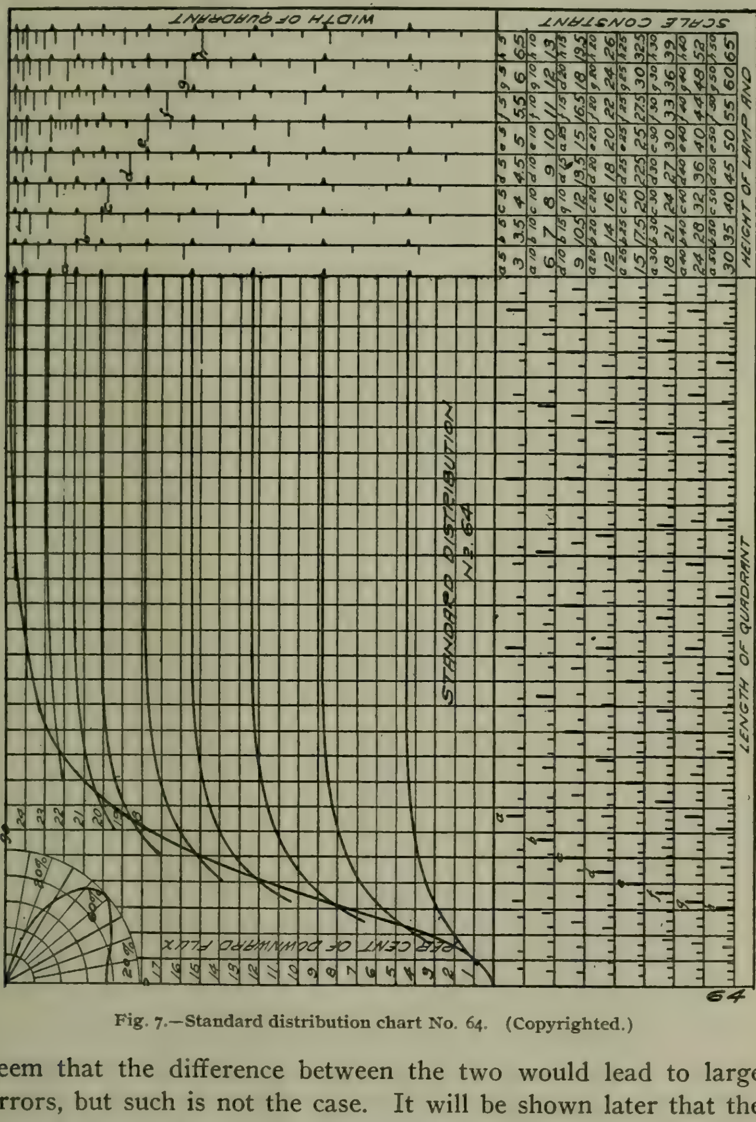


Fig. 7.—Standard distribution chart No. 64. (Copyrighted.)

seem that the difference between the two would lead to large errors, but such is not the case. It will be shown later that the error lies within practical engineering limits.

The room is considered to be divided into four quadrants about

each unit. Each unit is solved individually for the entire reading plane area, the quadrants being taken one at a time. In Fig. 5 the quadrant below and to the right of the unit No. 1 has a width of 4.25 ft. (1.3 m.) and a length of 5.7 ft. (1.74 m.). The height of the unit above the reading plane is 6 ft. (1.83 m.).

In the lower right hand corner of the chart, Fig. 7, is a table giving "height of lamp and scale constant." The large figures are heights, and the small letter and figure above each indicates the scales to be used and the values of the main divisions of the same. Thus the height, 6 ft., is found in the first column, second line of the tabulation. The "a" indicates that the upper "length of quadrant" scale has a value of 10 ft. at the main division marked "a," and also the left hand "width of quadrant" scale has the same value at the point "a." With this information other values of width and length are readily found.

TABLE I.

Lighting plan, Fig. 5.
Photometric distribution, Fig. 6.
Solid angle flux chart No. 64, Fig. 7.

Units	Quadrant dimensions Feet	Per cent. effective lumens
No's. 1, 2, 5 and 6	4.25 x 5.70	10.5
	5.70 x 11.25	16.5
	11.25 x 25.10	22.2
	4.25 x 25.10	14.0
		63.2
	Four units 4 x 63.2 = 252.8 per cent.	
No's. 3 and 4	4.25 x 15.40	13.6
	11.25 x 15.40	21.5
	11.25 x 15.40	21.5
	4.25 x 15.40	13.6
		70.2
	Two units 2 x 70.2 = 140.4 per cent.	

Total effective flux from six units	393.2 per cent.
Total lumens per unit	638.0
Total effective lumens	2509.0
Reading plane area 15.5 feet x 30.8 feet	477.0 sq. ft.
Average illumination	5.26 foot-candles

The flux in the 4.25 ft. x 5.7 ft. quadrant may now be found by finding where 4.25 comes on the width scale and noting where this point is in relation to the two nearest arrow heads on the opposite side of the line. In this particular case 4.25 ft. comes

almost exactly midway between two arrow heads, and the value of effective flux will accordingly be found midway between the two curves immediately to the left and directly above 5.7 ft. on the scale of lengths. This value is 10.5 per cent., read on the scale at the extreme left, and shows that 10.5 per cent. of the flux from unit No. 1 falls within the quadrant in question.

The solution for the entire installation is shown in Table I. The same "a" scales are used throughout, and the successive steps are similar to the one illustrated above.

As a matter of interest and to serve as a check on the calculated results, the experimental room previously mentioned was equipped with six outlets, and each provided with one 100-watt clear tungsten lamp and porcelain, enamelled steel reflector. The general arrangement of outlets is indicated in Fig. 5. The ceiling consisted of press board; three of the walls were brick, the fourth wall and floor of wood. The coefficients of reflection of the various surfaces, obtained by means of a Nutting's reflectometer, were as follows:

	Per cent.
Floor	18.7
Press board	73.7
Brick walls	67.0
Wood wall	64.5

The room was divided into fifty stations as shown on the plan of the room. Photometric observations were made at the center of each station with a portable photometer and the entire number averaged. In order to eliminate the direct light of the units from the photometric screen as a means of determining the illumination due to wall reflection, diaphragms were constructed consisting of blotting paper of approximately the same coefficient of reflection as the room and mounted on portable stands. These stands were moved about for each photometric station so as to shield the photometer screen from the direct light coming from the unit. The test results were as follows:

	Foot-candles
Total direct and reflected light	7.04
Reflected light	1.65
Direct light	5.39

And, as a comparison with the calculated data we have,

$$\text{Ratio} \quad \frac{\text{Calculated illumination}}{\text{Actual illumination}} = \frac{5.26}{5.39} = 0.98$$

TRANSACTIONS

OF THE

Illuminating Engineering Society

VOL. X NOVEMBER 20, 1915 NO. 8

CODE OF LIGHTING.*

FACTORIES, MILLS AND OTHER WORK PLACES.

Article I. Daylight.—All buildings hereafter constructed must be provided with adequate window area. Awnings, window shades, diffusive or refractive glasses must be used for the purpose of improving daylight conditions or for the avoidance of excessive brilliancy wherever they are essential to these ends.

The windows, skylights, saw-tooth or other roof lighting constructions, are to be arranged with reasonably uniform bays, and the daylight openings shall be so designed and proportioned that at the darkest part of any work space, when normal exterior daylight conditions obtain, there shall be available at least a minimum intensity equal to three times the minimum intensities given in Article V for artificial light.

(NOTE: The intensity requirements for daylight are higher than those for artificial light because the physical condition of the eye during the daytime is usually such as to require a higher intensity of natural light for satisfactory vision than is required at night under ordinary well designed artificial lighting systems.[1])

Article II. Old buildings at present constructed and not having adequate window area, must be provided with adequate artificial light according to the following articles, so as to supplement the natural light during normal daylight hours.

* For an amplification of the following articles of the code proper, see the Explanatory Rules on page 608.

[1] For detailed information on this daylight requirement, see Section I of the Explanatory Notes on page 609.

Article III. All buildings, whether old or hereafter constructed, must be provided during those hours of work when natural light is insufficient or not available, with adequate artificial light according to the following articles.

Article IV.—Adequate intensity of the light must be provided for each class of work, both on a horizontal plane as well as on a vertical plane passing through the work, according to Article V. In all cases, however, glare on working surfaces is to be avoided as it tends to reduce the visual efficiency of the workmen and to increase the likelihood of accidents.

Article V. Artificial Light; *Intensity Required.*—The average illumination intensity throughout any month actually measurable in foot-candles on a horizontal plane through the work is to conform to the following table. Uncertain cases which arise as to how to classify given manufacturing operations are to be left to the judgment of a lighting expert.

Class of work	Minimum foot-candles intensity	Desirable foot-candle intensity
Storage, passageways, stairways, and the like	0.25	0.25– 0.5
Rough manufacturing and other operations..	1.25	1.25– 2.5
Fine manufacturing and other operations....	3.50	3.5 – 6.0
Special cases of fine work..................	—	10.0 –15.0

Where operations are performed on the sides of the work in hand, they shall be classified according to this table, and if the illumination is furnished from an overhead system, it shall preferably *be not less than 50 per cent.* of the foregoing values, when measured on a vertical surface. If the illumination is furnished by an individual lamp or by lamps close to the work, the intensity shall conform to the minimum or desirable intensities required in the foregoing table.

(NOTE: As a guide to inspectors and others, it may be stated that with modern lamps roughly 1 candlepower per square foot produces an effective illumination of 3 foot-candles when the lamps are arranged according to the uniformly distributed overhead system, with mounting heights ranging from 12 to 16 ft. above the floor, and when the light is directed from said lamps to the work in an efficient manner. A rough idea may thus be secured of the candlepower per square foot necessary to conform

to the foregoing table of intensities by taking *one third of the intensity values given in the foregoing table.*)

Thus for fine manufacturing and other operations, the minimum foot-candle intensity is 3.5, which is approximately equal to 1.2 candlepower per square foot. The use of a portable photometer or illuminometer, however, is recommended for the determination of existing systems and all uncertain cases are finally to be established by these instruments.

Article VI. Lamps and machinery jointly, are to be so arranged as to avoid the casting of shadows over belts and other obstructions on important parts of the work, and the distribution of light from the lamps should be such as to avoid sharp contrasts of light and shade on the work.

Article VII. Inspection and regular maintenance of all lighting systems is required in spaces where work is being conducted, and in no case must the lighting devices, whether windows, lamps or auxiliaries such as globes and reflectors, be allowed to deteriorate, due either to dirt accumulations or to burned-out lamps, more than 20 per cent. below the minimum intensity values required by Article V.

Article VIII. Roadways, yards and places not usually frequented must either be provided by illumination during working hours when natural light is absent or partly absent, to make them safe against accident to employees traversing or engaged in such places, or a convenient control or controls must be placed at the entrance to basements, stock rooms, and the like, so that a person on entering can readily turn on the lamps beforehand.

Article IX. Stairways and passageways must be provided with lamps and reflectors or shades carefully located so as to shed their light generally over the entire space or spaces involved, and in sufficient quantity to make the stairways and passages safe against accident to employees traversing or engaged in such places. For intensities see Article V.

Article X. Each working space is preferably to be illuminated by lamps mounted overhead according to the system of general lighting, in preference to individual lighting. The overhead method of lighting, besides possessing many other advantages, also tends to reduce dark spots throughout the floor area, a

feature usually objectionable with the use of individual lamps. This particular Article is not an absolute requirement, but a suggestion enforceable at the discretion of a lighting expert.

Article XI. Auxiliary lighting should be provided in all large work spaces, such lamps to be in operation simultaneously with the regular lighting system, so as to be available in case the latter should become temporarily deranged.[2]

EXPLANATORY RULES.

The foregoing articles are supplemented by the following rules, which will aid in the observance of the requirements contained in the articles; tend to reduce eye trouble and accidents; and help in the securing of favorable results in planning lighting systems.

1. Lamps should be equipped with reflectors or shades for minimizing glare and economizing light. Bare lamps should not be used except in rare cases and then only when out of the line of vision.

2. As a general plan, mount the lamps high and out of the ordinary line of vision.

3. Although the types of reflectors and shades, and reflector and shade holders or fitters on the market are numerous, it is recommended that the holder or fitter, as well as the reflector or shade be selected with reference to placing the light source at the proper point in the reflector or shade so as to eliminate glare, due to exposure of the light source, and also for the purpose of directing the light from the lamp effectively to the work, that is, for obtaining a distribtuion of light which meets the desired requirements.

4. Light thrown vertically downward is not the only important component of the resulting illumination. The sides of machinery, machine tools and work, as well as horizontal surfaces often require good light.

5. Control few lamps in each group so that lamps not needed may be turned off conveniently.

6. Keep windows, lamps and reflectors clean since large losses of light result from the accumulations of dust and dirt.

[2] See Auxiliary Systems for Safety, Section XVI of the Explanatory Notes on page 640.

7. Provide a maintenance department if the shop is large enough to warrant it, so that all the items associated with the upkeep of the lighting system may be cared for systematically.

8. Keep ceilings and upper portions of walls a light color for the purpose of rendering both natural and artificial lighting more efficient and better diffused. The lower portions of walls should be a color which is restful to the eyes, preferably a medium tint, typified by the tint known as *factory green,* or a rather dark shade of yellow. Other medium tones are also available.

EXPLANATORY NOTES.

Section I. Daylight.—Adequate daylight facilities through large window areas together with light cheerful surroundings, are highly desirable and necessary features in every work place, and they should be supplied through the necessary channels not only from the humane standpoint, but also from the point of view of maximum plant efficiency.

Importance of Daylight.—The unusual attention to gas and electric lighting in factories, mills and other work places during the past few years; the perfection of various lamps and auxiliaries by means of which an improved quality and quantity of lighting effects are obtained; and the care which has been devoted to increasing the efficiency in various industrial operations;—all go to emphasize the many advantages and economies that result from suitable and adequate window space as a means for daylight in the proper quantities and in the right directions during those portions of the day when it is available.

Three Considerations.—Three important considerations of any lighting method are *sufficiency, continuity* and *diffusion.* With respect to the daylight illumination of interiors, *sufficiency* demands adequate window area; *continuity* requires (*a*) large enough window area for use on reasonably dark days, (*b*) means for reducing the illumination when excessive due to direct sunshine, and (*c*) supplementary lighting equipment for use on particularly dark days and especially towards the close of winter days; *diffusion* demands interior decorations that are as light in color as practicable for ceilings and upper portions of walls, and of a dull or mat finish in order that the light which enters the windows or that which is produced by lamps may not be absorbed

and lost on the first object that it strikes, but that it may be returned by reflection and thus be used over and over again. Diffusion also requires that the various sources of light, whether windows, skylights or lamps, be well distributed about the space to be lighted. Light colored surroundings as here suggested result in marked economy, but their main object is perhaps not so much economy as to obtain a result that will be satisfactory to the human eye.

Requirements.—The following requirements may now be listed for natural lighting:

1. The light should be adequate for each employee.

2. The windows should be so spaced and located that daylight conditions are fairly uniform over the working area.

3. The intensities of daylight should be such that artificial light will be required only during those portions of the day when it would naturally be considered necessary.

4. The windows should provide a quality of daylight which will avoid a glare due to the sun's rays and light from the sky shining directly into the eye, or where this does not prove to be the case at all parts of the day, window shades or other means should be available to make this end possible.

5. Ceilings and upper portions of walls should be maintained a light color to increase the effectiveness of the lighting facilities from window areas. The lower portions of walls should be somewhat darker in tone to render the lighting restful for the eye. Factory green or other medium colors may be used to good effect.

Classification.—Means for natural lighting may be classed under three broad divisions as follows:

(*a*) That case in which the windows are located on the sides of the building or in the framework of saw-tooth construction, where diffused light from the sky reaches the work during a large portion of the day.

(*b*) That case in which windows are located overhead on a horizontal or nearly horizontal plane in the form of skylights, thus furnishing direct light from the sky during a large portion of the day.

(*c*) That case in which prismatic glass takes up the direct light from the sky and redirects it into the working space.

Method (*a*) is, of course, the most common of the three, and it may be noted that the saw-tooth or other roof lighting constructions have become very popular and result in an excellent quality and quantity of light for given window areas provided the size and location of windows are in accord with modern practise.

Increasing the Value of Floor Space.—Adequate and well dis-

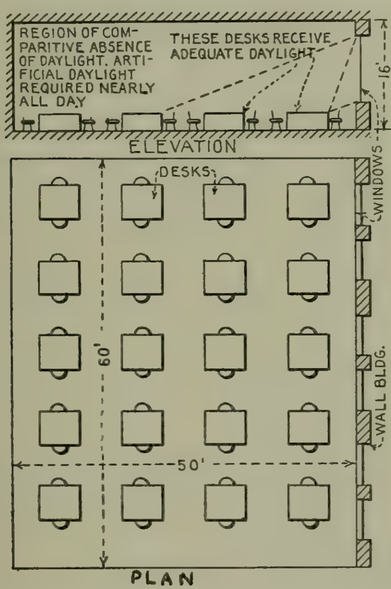


Fig. 1.—Diagram of a large office with windows on one side only.

tributed natural light means that certain portions of the floor space which ordinarily would not be available for work, are converted into valuable manufacturing space. In a general way, therefore, the average factory, mill or other work place, if properly designed, should possess natural lighting facilities which produce the best practicable distribution of daylight illumination.

Wide Aisles.—With low ceilings and very wide aisles, workmen located at the central portion of the building must sometimes depend for their natural light on windows located at a considerable distance away from their working position. In these cases

it may be impossible, in general, to depend altogether on daylight over an entire floor space, even at those times of the day when daylight conditions would be entirely adequate under other circumstances. This statement applies to side windows rather than to skylights or to saw-tooth construction. Fig. 1 illustrates this feature.

Varying Conditions.—In a case of this kind, employees located next to the windows are furnished with suitable daylight in the early morning and towards the latter part of the afternoon, the upper portions of the windows being particularly serviceable in lighting areas at some distance away from the windows. A southern exposure, however, results in such excessive light from the sky during the middle of the day, that heavy shades are nearly always pulled down so as to cover the entire window area. This plan makes it necessary to use artificial light throughout the larger part of the office during the brightest portion of the day, and reduces the daylight at those points where it would supposedly be the best, namely, near the windows. Here the location of the windows is a large factor in the excellence of the daylight conditions, but the manipulation of the shades is perhaps even more important. To avoid such a difficulty, adjustable translucent upper window shades with adjustable opaque lower shades might be employed.

Upper Portions of Windows.—It should be further noted in this illustration that the upper portions of the windows give a reduced illumination in proportion to their areas, to the floor space near them. In rooms of moderate size, therefore, the windows should be placed as near the ceiling as practicable. When the sun shines through windows so located, the direct light must be reduced or diffused. This may be accomplished by the use of ribbed glass in ordinary factory and mill buildings, and in offices by the use of translucent sun shades or awnings.

Tempering the Light.—The light due to the sunshine on such shades and awnings will be as bright as ordinary skylight if the shade is well chosen, and the ribbed glass will be still brighter. If the windows are large, the illumination is likely to be too great near the windows as previously pointed out and it must be reduced. This should not be done, however, by pulling down an

opaque shade over the top of the windows because the top portion of the window is the part that is particularly needed to give light to the interior of the room. The better scheme is to employ an opaque shade *which should be raised from the bottom of the window.* This will reduce the illumination near the window without affecting it over the interior of the room to any marked degree.

Bench Locations.—Fig. 2 shows how benches are commonly located with respect to windows, so that the light received on the work may be most satisfactory. This sets a certain limitation upon the possible arrangement of the work over the floor space, depending on the way the daylight is furnished to the floor area.

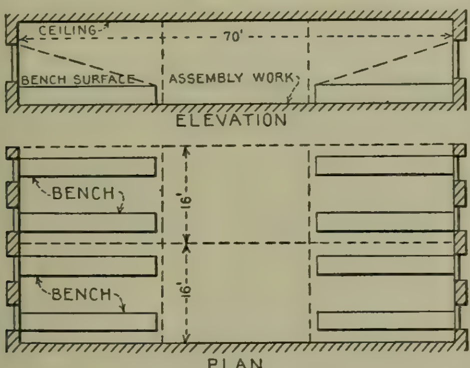


Fig. 2.—Diagram showing benches located with respect to the windows so as to receive the natural light advantageously.

This limitation can be eliminated almost completely in the case of artificial light through a uniform distribution of lamps overhead. This statement applies to those cases where natural light is transmitted through side windows, and includes a feature specially noticeable in buildings of more than one story. In contrast, the work may be arranged almost independently of the natural light in buildings where the natural light is furnished by overhead windows or through the means of saw-tooth construction.

Window Glasses.—Both translucent and clear glass are employed for factory and mill windows. There is a slight reduction in the transmitted light through ordinary translucent wire glass,

but it is often required by insurance regulations for a reduction in the fire risk where a given building is located in close proximity to other buildings. Wire glass is also used quite generally with steel window frames, here being an added protection from the standpoint of fire risk. Wire glass may be obtained in clear form, but its expense in contrast to the translucent form is such as ordinarily to prohibit its use for industrial purposes.

Wire Glass.—Wire glass, also known as ribbed glass, should be used and is advocated for practically all factory and mill windows where prisms are not required. Wires of rather open mesh cause so little reduction in light as to warrant no mention of this feature. Special care should be taken to get such glass as is smooth both on the flat side and on the ribbed side to facilitate cleaning. Wire or ribbed glass gives better diffusion than plain glass.

Prism Glass.—Where the sky outside of the windows is obstructed by buildings, prism glass is recommended if the room is deep. Different kinds of prisms cannot be used to advantage interchangeably. The amount of prism glass required in any case depends much upon the surroundings and to obtain excellent results, of which such glass is capable, it must be used intelligently.

Skylights.—Skylights are sometimes installed in long narrow continuous strips in a sloping roof. The ribs of the ribbed glass are generally so arranged that it is convenient to make them at right angles to the length of the strips. The result is that the sunshine is diffused by the ribs over a narrow area parallel to the strip of skylight, thus lighting one part of the room much more brilliantly than the remainder. If the ribs are installed to run parallel to the strips, they will give a much more general distribution of the sunlight. In the foregoing, the word *strip* refers to the long belt of skylight and not to the individual sheet of glass. Ribbed glass in vertical windows should generally be placed with the ribs horizontal. They thus roughly fulfill some of the functions of prisms.

Dirt Accumulations.—While translucent wire or ribbed glass reduces the amount of light transmitted through the windows, the roughness of the outside surface of such glass often causes

accumulations of dust and dirt, which are more to blame for the reduction of transmitted light in some cases than the translucent nature of the glass itself. Remedies of this difficulty are to secure smooth glass and to restort to frequent cleaning.

Wire Glass as a Safeguard.—Wire glass for skylights is, of course a practical necessity as a safeguard against accidents due to accidental breakage of the glass or due to objects falling on top of the glass.

Calculations for Natural Light.—In certain typical localities, the average brightness of the sky during business hours is about 250 candles per square foot. This is probably a fair average value for the entire United States. The lower or minimum value of sky brightness, excluding particularly stormy days, may be taken as about 100 candles per square foot. Allowing for a reduction of 25 per cent. for losses in the windows themselves, the brightness of the sky as seen through a window becomes equal to a minimum of say 75 candles per square foot in any directions from which the sky can be seen through the windows. This brightness value if multiplied by the part of the window area through which sky is visible from a given point in the work space gives the available candlepower through the window in question, and this candlepower is then divided by the square of the distance between the given point and the window to obtain the foot-candle intensity of the illumination at the given point.

Method illustrated.—To illustrate this method, consider a hallway 40 ft. long, lighted by a window 5 ft. by 5 ft. at one end, with the sky visible from the darker end of the hall through the upper half of the window only. The illumination at the dark end of the hall will then be equal to:

$$5 \times 5 \times 0.5 \times \frac{75}{1{,}600} = 0.58 \text{ foot-candles,}$$

under the assumed window brightness of 75 candles per square foot. The 1,600 in this calculation results from the square of 40 ft., the length of the hall, or in other words the distance from the point considered to the window; and the factor 0.5 takes into account the fact that the sky is visible through only one half of the window area from the point considered.

Checking the Intensity.—The intensity is not sufficient at this

darkest part of the hall since the requirements of Article I of the Code proper call for three times the minimum values given in Article V, and the minimum value given in Article V for passageways is 0.25. Three times this value is 0.75 which is somewhat greater than the value found in this calculation. The window area must therefore be increased in size by about 50 per cent., or if this is impossible or impracticable, the hallway must be provided with artificial light at those points where the natural light falls below the requirement.

Calculation for a Skylight.—As another illustration, assume that fine manufacturing work is to be performed under a skylight 20 ft. above the work. If the brightness is assumed to be 75 candles per square foot as before, the minimum intensity must be 3 × 3.5 foot-candles, that is, 10.5 foot-candles, based on the requirements of Article I of the Code. The window area must then equal:

$$10.5 \times \frac{400}{75} = 56 \text{ sq. ft.}$$

Part of Window Area to Consider.—It is important in estimating the illumination of any work room to consider only that portion of the window area through which clear sky is visible, provided the window is equipped with ordinary clear glass.

Sunshine Not Desirable.—In all the work of providing natural light, it should be kept in mind that direct sunshine in itself, from the illumination standpoint but irrespective of sanitary conditions, is not wanted. The idea that sunshine is the important item is a common but an erroneous impression. For example, in saw-tooth construction, the windows do not face the south to get all the sunshine possible, but they face the north to exclude the sunshine. Ordinary windows, on the other hand, face all directions because not enough light can be distributed to interiors from north windows alone. Windows on the other than north fronts admit sunshine to be sure, and this makes sun shades and awnings necessary to exclude the excessive brightness.

Section II. Value of Adequate Illumination.—Factory and mill owners are concerned in the matter of securing the largest output for a given manufacturing expense. An improved machine tool capable of increasing the product for given labor costs is most

attractive, provided its first cost is within returnable limits out of the larger profits. Improved small tools, better methods of handling material, adequate crane service, fire protection, good shop floors, accurate and efficient time-keeping methods, and similar items, vitally concern the shop manager; money is expended to realize excellence in these features because they afford increased economies and protection, thus resulting in a higher efficiency of the plant.

Energy Consumption a Minor Item.—Many arguments leading to the sale of gas and electric lamps for use in factory and mill buildings are based on reducing the lamp operation cost by substituting a new for an older system. Arguments of this kind are of value, however, only when such a reduction in operation cost can be effected without sacrifice in the adequacy of the illumination. It would be a poor policy, in the extreme, to argue a saving in energy consumption by the substitution of one type of lamp for another on a basis of equal candlepower in both old and new systems.

Effect of Good Light on Production.—Arguments of a convincing nature, which insure to the factory or mill manager an increased output through improved illumination service, are of importance and even greater at times than reductions in the cost of illumination for the same quantities of light. In view of the fact that resulting advantages of superior illumination on increased output are apt greatly to exceed economies in operation cost as regards the lighting system, it is a distinct advantage to direct and hold the attention on the former rather than on the latter. This statement will be more apparent when interpreted into definite items as follows:

Advantages of Good Light.—While the necessity of good natural and artificial light is so evident that a list of its effects may seem commonplace, these same effects are of such great importance in their relation to factory and mill management, that they are well worth careful attention. The effects of good light, both natural and artificial, and of bright and cheerful interior surroundings, include the following items:

1. Reduction of accidents.
2. Greater accuracy in workmanship.

3. Increased production for the same labor cost.
4. Less eye strain.
5. Promote better working and living conditions.
6. Greater contentment of the workmen.
7. More order and neatness in the plant.
8. Supervision of the men made easier.

In this list it will be noted that items 4, 5, 6, 7 and 8 all have a bearing on accident prevention.

Interpreting the Advantages of Good Light.—While the major consideration in the eyes of the factory or mill owner is undoubtedly and quite naturally the money value of good light in the larger return of both quantity and quality of work which may result from the installation of a superior as compared with an inferior lighting system, it should be noted that it is very difficult to interpret into dollars and cents the value of good light made possible by such returns. This difficulty is due to the necessity of keeping all conditions in a factory or mill section absolutely constant while varying the amount of illumination from poor to good conditions, in an effort to determine the output and its dependency on the lighting facilities. *As accurate data becomes available,* giving the increases in production for certain specific improvements in artificial lighting, it will doubtless prove helpful to a proper interpretation of adequate light and its worth to any plant.

The eight foregoing points are emphasized as forming the most important features in the problem of good lighting. Although difficult to interpret into money values, and somewhat intangible, they are indisputable arguments in favor of the best available illumination from the standpoint of the factory or mill owner.

Practical Example.—Continuing from the manufacturer's point of view, it may be said that certain assumptions as to energy cost, cleaning, interest and depreciation, show that the annual operation and maintenance cost for the illumination of a typical shop bay of 640 sq. ft. area, may be taken at $50.00. If five workmen are employed in such a bay at an average wage of say 25 cents per hour, the gross wages of the men in such a bay, plus the cost of superintendence and indirect shop expense, may equal from

$5,000, to $7,000 per annum. In a case of this kind, therefore, the lighting will cost from 7/10 to 1 per cent. of the wages, or the equivalent of less than 4 to 6 minutes per day. We may roughly say that a poor lighting system will cost at least one half this amount (sometimes even more through the use of inefficient lamps and a poor arrangement of lamps), or the equivalent of say 2 to 3 minutes per day. Nearly all factories and mills have at least some artificial light, hence, in general, if good light enables a man to do better or more work to the extent of from 2 to 3 minutes per day, the installation of good lighting will easily pay for the difference between good and bad light, through the time saved for the workmen.

Actual Losses.—Superintendents have stated in actual instances, that due to poor light their workmen have lost much time, sometimes as much as from one to two hours per day or certain days. If good light will add an average of say one-half an hour per day to the output, these 30 additional effective minutes represent an increase in output of 5 per cent., brought about through an expenditure equal to ½ of 1 per cent. of the wages for improved lighting, or a saving equal to ten times the expense.

Safety.—While these features are of special interest in the eyes of the manufacturer, the principle item to consider, perhaps, from the legislative side of the question, is the necessity of an act or acts to provide employees of workshops with proper and sufficient illumination from the standpoint of safety. The legal aspect of the safety question in its relation to illumination in factory and mill buildings is a topic of unusual importance.

Section III. Old and New Lamps.—The inadequate means available for illumination by artificial methods in the past have contributed to the slowness of an appreciation of the features of artificial light which influence the working efficiency of the eye. Open flame gas burners, carbon incandescent and arc lamps, practically the only illuminants available ten years or so ago, play but a small part in the present approved methods of factory and mill lighting.

New Lamps.—The large variety of comparatively new lamps available for factory and mill lighting includes the mercury vapor, metallized filament, tungsten, gas filled tungsten, metallic flame

or magnetic arc, the flame carbon arc, the quartz mercury vapor, and various types of gas arc lamps. Remarkable improvements have thus been made in both the electric and gas lighting fields, the same general rules of applying the lamps covering both of these fields. Possibilities in factory and mill lighting are now attainable which, before the introduction of these new lamps, were either unthought of or impossible. Consideration of the eye as a delicate organ, together with the new ideas of the items which affect its comfort and efficiency, have resulted in establishing certain principles in illumination work, and have directed attention naturally and in a growing manner to the proper use and application of these new lamps.

Section IV. Effects on Factory and Mill Lighting Produced by Modern Lamps.—With the introduction of these new gas and electric lamps, broader possibilities have been presented in factory and mill lighting. The use of units of sizes adapted to the purposes, allows results which it has been hitherto impossible to obtain satisfactorily, either by the arc lamp, carbon filament or open flame gas burner, formerly available.

New Possibilities.—It is evident that the introduction of the many new lamps has made possible what may be termed a new era in industrial illumination, a distinctive feature of which is the scientific installation of the lighting units, suiting each to the location and class of work for which it is best adapted. Before the availibility in recent years of medium sized gas and electric units the choice of the size of unit for a given location was often no choice at all. In many cases, due to small clearance between cranes and ceilings, or other conditions making it necessary to mount the lamps very high above the floor, but one size or type of unit was available, the carbon filament or open flame gas burner in the former, and the arc lamp in the latter case.

Low Ceilings.—For low ceilings, up to 18 ft., the use either of carbon filament, open flame gas burner, or arc lamps resulted usually in anything but uniform light over the working plane, and often produced merely a low general light which was practically useless for the individual machine. In such instances, individual lamps had to be placed over and close to the machines. With this arrangement, relatively small areas are lighted by each lamp, and

the metal shades usually employed, serve only to accentuate the "spot lighting" effect. Such a form of illumination for factory and mill work is unsatisfactory and inefficient, but as stated, was in the past, in many cases, the only available scheme. *The absence of lamps of the proper size is no longer an excuse for the existence of such conditions in industrial plants.*

Section V. General Requirements of Artificial Lighting.—The following requirements for factory and mill lighting are made all the more important by the peculiar limitations and the wide variety of conditions to be found in factory and mill buildings and in factory and mill work:

1. Sufficient illumination should usually be provided for each workman irrespective of his position on the floor space.

2. The lamps should be installed and selected so as to avoid eye strain to the workmen.

3. The lamps should be operated from sources of supply which will insure reliable illumination results, particularly on account of the demoralizing effect produced by intermittent service, just when the light may be most needed.

4. Adequate illumination should be provided from overhead lamps so that sharp shadows may be prevented as much as possible, and in such measure that individual lamps close to the work may be unnecessary except in special cases.

5. The type and size of lamp should be adapted to the particular ceiling height and class of work in question.

6. In addition to the illumination provided by overhead lamps, individual lamps should be placed close to the work if they are absolutely necessary in the eyes of a lighting expert, and in such cases the lamps should be provided with suitable opaque reflectors.

These requirements may now be met by means of the new types of gas and electric lamps, one type of which can usually be found for practically each factory and mill location, specially adapted to the general physical conditions of the location as typified by the clearance between cranes and ceiling and other similar items.

Section VI. Overhead and Specific Methods of Artificial Lighting.—Factory and mill lighting may be classified under two

general divisions: first, distributed illumination furnished from lamps mounted overhead; and second, specific illumination furnished by individual lamps located close to the work. For practical purposes this classification is sufficient. In numerous cases a combination of these two methods becomes necessary.

Mounting the Lamps High.—Where the lamps are high enough to be out of the line of ordinary vision, and are of a size and so spaced as to furnish illumination at any position of the floor where work may be carried on, the system is referred to as the *overhead method* of lighting. This method has many advantages. Its general adoption, which has been somewhat slow, has increased with the appearance of the many new types of lamps and with the growing appreciation of the value of good lighting.

Where a small amount of general or overhead lighting is coupled with specific lighting from individual lamps, a large part of the floor space in many shops is in relative darkness, and much dependence must be placed on the hand lamps close to the work. The small number of overhead lamps generally used in such cases, furnishes merely a small amount of additional illumination over the floor space which is not sufficient to be of much value. However, where sufficient intensity is provided by general illumination, this is often a very effective means of lighting a large work-room.

Low Ceilings.—Locations with low ceilings, until recently, have been lighted by the individual hand lamp method, because the old carbon filament lamps, being of low candlepower, could not well be used close to the ceiling, while the old type of arc lamp was often impracticable, due to its large physical size, as well as its relatively high candlepower. This statement is subject to some modification, because low candlepower units have sometimes been used in clusters for low ceilings as a compromise between a single small or a single large unit, this scheme being, however, usually insufficient and unsatisfactory in comparison with modern methods of lighting. In a particular manner, therefore, suitable illumination has been difficult with low ceilings.

New types of gas and electric lamps have a range of candlepower from very low to very high values, and the overhead system with the elimination of individual lamps is thus possible;

in other words, a size of gas or electric lamp may now be selected from a large available list of sizes for nearly every factory or mill condition.

Section VII. Various Locations Illustrated.[3]—Figs. 3 to 12 inclusive are given to indicate how the problem of adequate illumination has been solved in a number of actual instances, and the following notes apply to some of the considerations involved.

There are two main items to consider in deciding for or against high candlepower lamps for the factory or mill. First, how high are the lamps to be mounted; and second, will the light at any given point on the machines or other operations be satisfactory if it comes from a few lamps or should it come from many sources? If the ceiling or overhead construction is under 16 ft., lamps of high candlepower can hardly be used in sufficient numbers to produce uniform illumination over the floor space. If they are to be mounted at a height between 16 and 25 ft., it is largely a question of whether light from a relatively few lamps will produce satisfactory results. For mounting heights over 25 ft., lamps of high candlepower possess some advantages, chief of which is their large volume of light for given energy consumed, always provided the light is effectively directed towards the floor.

Three Groupings.—These three groupings by mounting heights are conveniently shown in Figs. 15, 16, 17 and 18. In Fig. 15, a single shop bay with a ceiling height of 12 ft. is shown as typical of the first grouping. The single high candlepower lamp furnishes approximately the same amount of light to the machines as do the eight small lamps. Note, however, that the illumination from the large lamp is not nearly as uniform as that from the small lamps, although the spacing of both the small and the large lamps as represented in this illustration is typical of many actual installations. Note also, that the shadows cast by the large lamp at certain portions of the floor space must be so marked as to make the illumination it furnishes very inferior in this respect to the illumination from the smaller lamps, because of their larger number.

Here, if the number of large lamps for the given floor area be

[3] Figs. 3 to 12 inclusive are, in general, arranged in the order of their mounting heights. The low mounting heights are shown in the earlier illustrations and the higher mountings in the later views.

increased in an endeavor to make the illumination more uniform and to reduce the shadows, the expense, as compared with that for smaller lamps, makes the large lamps a very unfavorable proposition. These two features are the basis for stating that in general large lamps are not desirable for mounting under 16 ft., and an analysis of conditions, together with a careful and unbiased comparison with the illumination produced by smaller lamps, will nearly always bear out this conclusion.

Second Grouping.—In Fig. 16, a 20 ft. ceiling has been selected as typical of the second grouping, a single shop bay being shown. Here the work is assumed to be rough assembly, mostly on horizontal surfaces, and the single high candlepower lamp, besides giving more nearly uniform illumination, because the light is distributed more broadly due to the increased height, is correspondingly more satisfactory as to shadows produced by the large lamp in the preceding illustration (Fig. 15), on account of the improved direction in which much of the light reaches the work. In this case, the arrangement of both large and small lamps is typical of many existing installations.

In Fig. 17, however, although the height is the same as in Fig. 16, the work is quite different, being conducted on the inside of large vertical tanks. It would obviously be impossible to perform this work by the light from the single large lamp as well as with that from the larger number of medium sized lamps, even if the actual amount of light from each was the same, on account of the poor direction of the light at certain positions of the work from a single unit in such a case. The medium sized lamps furnish approximately the same quantity of light and yet no matter where the tanks may be placed, they will receive considerable light from the medium sized lamps directly over or nearly over them, at least far more than is apt to reach them from a single unit in every other bay (the assumed arrangement of the large lamps).

For this second grouping of mounting heights, then, the large lamp may or may not be adapted, depending on whether the reduction of shadows is of much importance, as is the case in Fig. 17. The large lamp is, however, more likely to be satisfactory here than in the first case (Fig. 15), because of the better

Fig. 3.—Night view of a rather low factory section showing tungsten lamps of the 250-watt size mounted 12 ft. above the floor. Note the original individual lamps over the machines.

Fig. 4.—Night view showing mercury-vapor lighting in low factory section. The lamps are about 12 ft. above the work. Note the comparative absence of shadows.

Fig. 5.—Day view of a gas lighting installation in a low factory section. This photograph shows merely the general arrangement of lamps and gives no idea of the illumination effect.

Fig. 6.—Night view of a planing mill showing an installation of 250-watt tungsten lamps with a 16 ft. mounting. Note the excellent distribution of the light and the comparative absence of shadows. This is an example of the overhead method of lighting.

Fig. 7.—Night view of a boiler shop.

Fig. 8.—Day view showing arrangement of gas lamps in a medium high factory space. Note the pierced reflectors over the machine tools near the center of the picture.

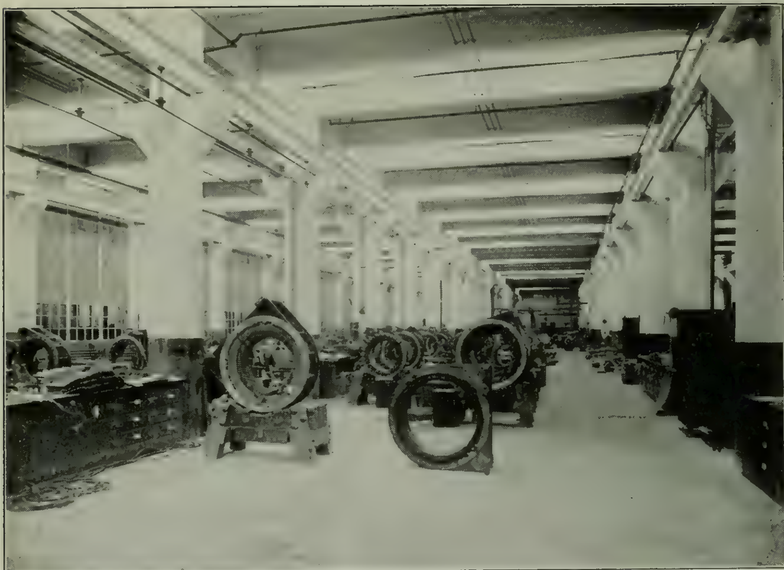


Fig. 9.—Night view of factory section with relatively high mounting of 250-watt tungsten lamps. The lamps are 20 ft. above the floor. Note the excellent distribution of the light and the shielding effect of the girders which serve to reduce the glare as one looks down the aisle.

Fig. 10.—Night view of arc lamp installation with 40 ft. mounting at center of picture, and 20 ft. at sides. Excellent distribution.

Fig. 11.—Day view of relatively high section, showing a system of gas lighting.

Fig. 12.—High section showing a system of mercury-vapor lamps. Note the excellent distribution of light over the floor area.

Fig. 13.—Excessively bad lighting. Bare lamps produce a glare which is harmful and renders the illumination very ineffective. Compare with Fig 14.

Fig. 14.—Example of good tungsten lighting with metal reflectors. Note the row of lamps near the ceiling for producing general illumination. This is known as combined general and localized illumination. Compare with Fig. 13.

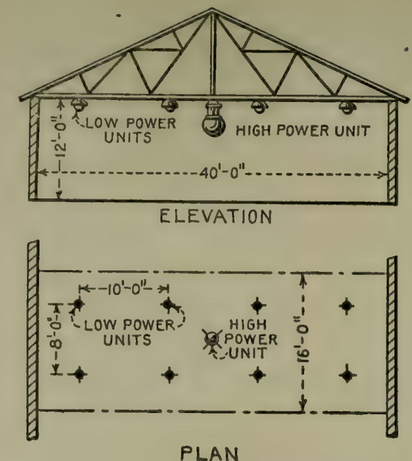


Fig. 15.—Diagram showing alternate schemes for lighting a low factory section. This con trasts the use of large and small lamps for a mounting height of 12 ft.

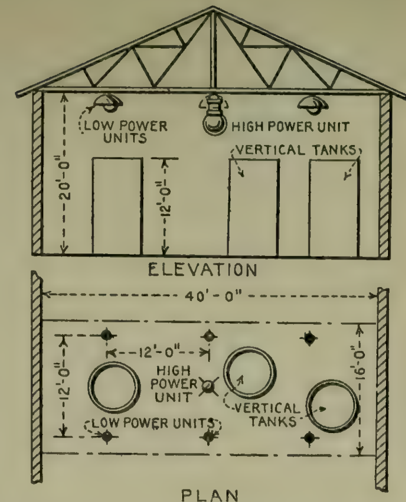


Fig. 16.—Diagram contrasting the use of large and medium size lamps for mounting height of 20 ft.

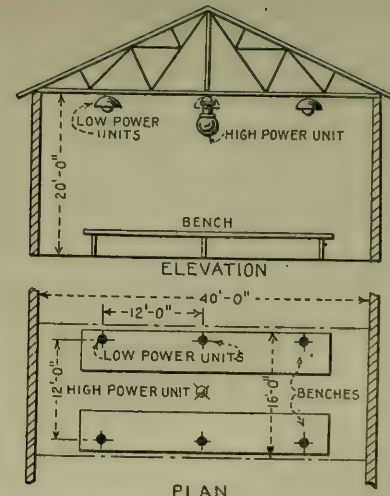


Fig. 17.—Diagram of same factory space shown in Fig. 16, but with a different class of work. This view contrasts the use of large and medium sized lamps for a 20 ft. mounting.

distribution of the light due to the higher mounting, a fact made evident in Figs. 15 and 17 on account of the decreased number of small lamps and the increase in their size made possible in Fig. 17 as compared with Fig. 15, where the mounting is lower. By the same line of argument, it can be shown that for higher mountings, large lamps are still more likely to prove satisfactory.

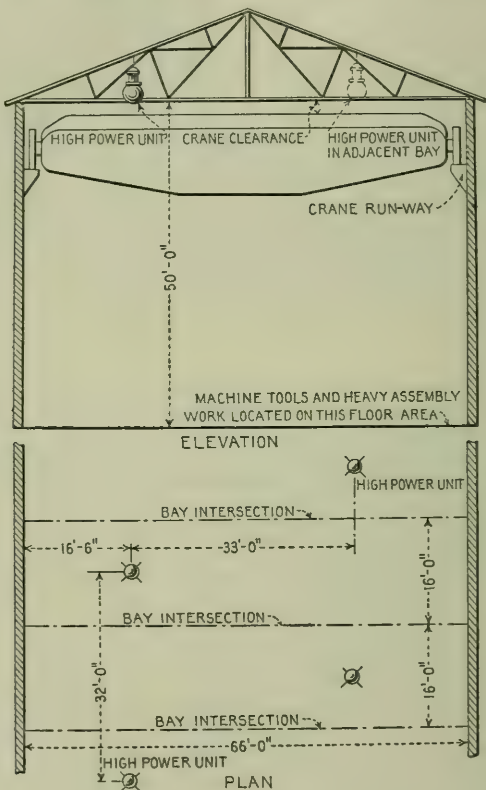


Fig. 18.—Diagram showing the use of large lamps for a mounting height of 50 ft.

In Fig. 17, the number of large lamps might have been increased for the given floor area, but to have done so would mean that the cost for the lamps themselves and for the energy and upkeep to maintain them would be excessive in comparison with the smaller types of lamps.

Third Grouping.—In Fig. 18, the third grouping of mounting heights is shown with the lamps about 50 ft. above the floor. In

this illustration the distribution of the light from the large lamps will be far more satisfactory both for flat and tall work than in the two preceding cases. It will be noted further that the increased height of the lamp causes the light to fall in such directions as to evenly distribute it over the entire floor space taken care of by this one lamp in much better shape than for the lower mounting heights. (See also Figs. 19 to 21 inclusive.)

Section VIII. Lighting Circuits for Electric Lamps and Supply Mains for Gas Lamps.—The question of lighting circuits is mentioned here with particular reference to factory and mill condi-

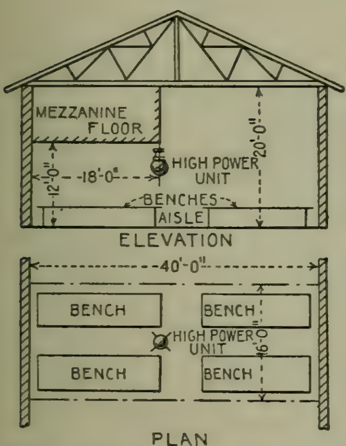


Fig. 19.—This shows a very poor arrangement of artificial lighting by means of large lamps mounted too close to the floor. Compare this poor lighting scheme with the improved plan in Fig. 20.

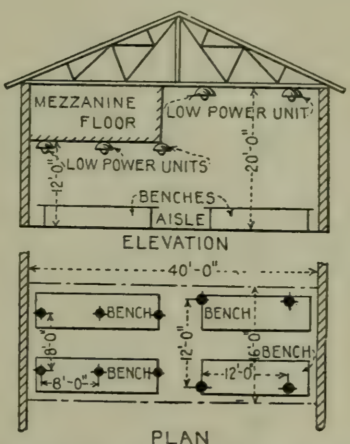
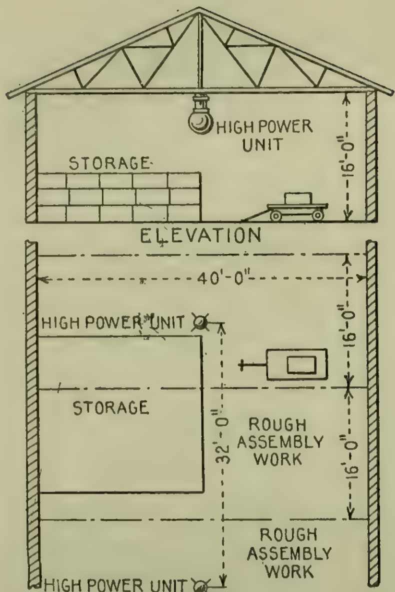


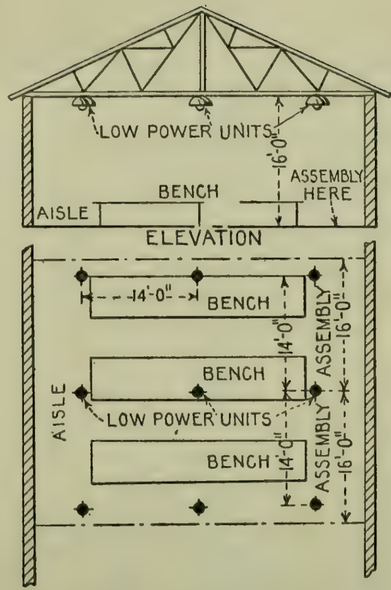
Fig. 20.—This illustration is to be compared with Fig. 19. It indicates an improved scheme over that shown in Fig. 19, made possible by the use of smaller lamps

tions, where motor loads are apt to be large in comparison to the energy consumption of electric lamps which are in service. In some cases, the proportion of motor load to lighting load is in the ratio of 10 to 1, in others 7 to 1, and so on, and the varying demands on the circuits by motors may greatly affect the lamps. Hence it is important to maintain strictly separate supply circuits for the lamps in order to avoid varying voltage which is apt to result if the motors are connected to the same circuits with the lamps.



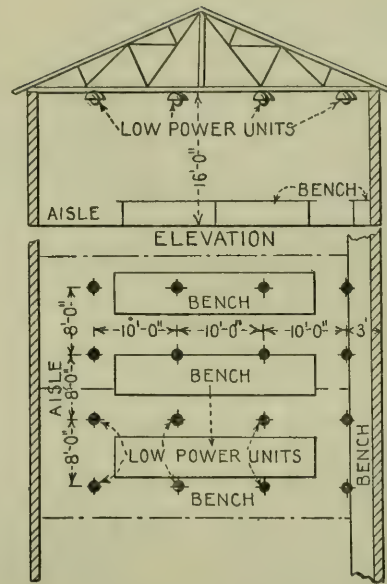
PLAN

Fig. 21.



PLAN

Fig. 22.



PLAN

Fig 2 .

These three illustrations show various ways in which a factory space with 16 ft. girder clearance can be handled, depending on the class of work preformed. The first case, Fig. 21, is fairly satisfactory for storage spaces, and either the the second or third cases, Figs. 22 or 23, can be employed for bench assembly or manufacturing. The third case, Fig. 23, is to be preferred where the class of work consists of the handling of small machinery parts.

Constant Voltage.—In addition to the superior illumination resulting from lamps supplied from constant voltage mains, some types operate with longer life or very much better mechanically when supplied with constant voltage than otherwise. These features will therefore generally more than offset the somewhat greater cost of maintaining separate circuits for each class of service. In like manner and for similar reasons, it is advisable to place gas lamps on supply lines separate from those delivering gas for power purposes.

Section IX. Control of Lamps and Arrangement of Switches.— The control of lamps in factory and mill lighting is important in all cases, but specially so where a large number of lamps is used in preference to a small number for a given floor area. For example, where an overhead system of tungsten lamps of small size is used, a large number will, of couse, be necessary for a given floor area, and in such cases the number of control circuits may at times seem excessive when planned out for sufficient flexibility of operation. Such circuits, however, in rendering the system more flexible, will be more than paid for by the saving in energy and maintenance due to the turning out of lamps not needed in certain sections of the factory or mill, provided the number of hours per day during which the lamps are used on the average is relatively large, and the differences in daylight intensities over the floor area is also relatively large.

Control Parallel to Windows.—The lamps most distant from the windows will usually be required at times when the natural light near the windows is entirely adequate, thus making it an advantage to arrange the groups of lamps in circuits parallel to the windows. The advantage of this method is further apparent when it is considered that if the lamps are controlled in rows perpendicular to the windows, all lamps in a row will necessarily be on at one time, while a portion only may be required.

Practical Case.—The foregoing statement may be developed into a definite proposition. Thus, to install a single switch may involve say $5.00 as its first cost. If ten lamps are to be controlled from a single switch, these ten lamps must obviously either all be turned off at a time or all turned on at a time. An additional switch at a cost of $5.00 will permit either half of these

ten lamps being turned off, if not required at certain times when the remaining five are needed. This extra switch may or may not be an economy. Consider, for example, the case where these five lamps are of the 60-watt tungsten type, and that they are turned off by the extra switch on an average of one-half an hour per day while the others are needed, or *vice versa*. In a year's time, the energy saved at 1 cent per kilowatt-hour, will amount to perhaps 50 cents. At this rate it will require ten years for the energy saved to pay for the first cost of the extra switch. This would not be considered a distinct economy. If, however, the energy cost be greater, and more nearly the average under actual conditions, or if the number of hours per day during which a portion only of the lamps will not be used, be greater, then these values will be correspondingly modified.

Locating Switches and Controls.—In locating switches or controls in factory and mill aisles, care should be exercised to arrange them systematically, that is, on columns situated on the same side of the aisle and on the same relative side of each column. This plan materially simplifies the finding of switches or controls, by those responsible for turning on and off the lamps, and is particularly important where a given floor space is illuminated by a large number of small or medium sized lamps distributed uniformly over the ceiling area, a feature which is usually accompanied by the use of a relatively large number of switches or controls.

Section X. Systematic Procedure Should be followed in Changing a Poor Lighting System Over to an Improved Arrangement.—When undertaking the change from an old to a new lighting system, the various forms of illumination which are adapted to factory and mill spaces should be studied, and an investigation made of the various types of gas and electric lamps on the market which are available for the purpose.

Time should be allowed for a study of the given locations to be lighted; for preparing the plans of procedure in the installation of the gas or electric lamps and auxiliaries; and for customary delays in the receipt of the necessary supplies and accessories to the work in hand. Altogether, therefore, work of this kind requires considerable time for its completion.

Using the Shop Force.—In large factories or mills, a wiring or gas fitting force is sometimes a part of the maintenance division. The work of the wiremen or fitters is likely to be heaviest in the winter due to the dark days. Where this condition exists, there is all the more reason to apportion out new work so as to accomplish it during the months of least wiring and piping repair activity, and further, at that time of the year when employees will be comparatively unaffected by the disturbances usually associated with a change from an old to a new lighting system through possible irregularities in the illumination service while the wiremen or fitters are at work.

Distribution of Expense.—Another feature different from the foregoing viewpoint, is in the distribution of the installation cost over a relatively long interval. If, for example, the system is desired for the approaching winter, the complete wiring or piping plans may be drawn up and blocked out into three, four or even more sections, thus spreading the expense over as many months.

Yearly Appropriation.—In some shops a given appropriation may be allotted each year for building equipment. From the standpoint of finance plans, it may thus be desirable to distribute outlays of this nature over the year, ıather than to concentrate them at any one time. *An important consideration in this method of installing lamps, however, is to prepare in as far as possible the complete plans in advance, at least as regards given factory or mill sections, so as to insure a uniform and symmetrical installation as a whole when the component parts are finished.*

Section XI. Reflectors and Their Effect on Efficiency.—A reflector or shade is used in conjunction with a lamp for the purpose of reducing the glare otherwise caused by looking directly into the bare lamp, as well as for the purpose of redirecting the light most effectively to the work.

Reflectors and shades are now obtainable so designed as to be specially adapted to give sizes and types of the smaller and medium sized line of lamps, and hence care should be used to be sure that both reflectors and lamps are of the correct size in their relation to each other. This is of the utmost importance in securing uniform illumination for a given spacing distance and mounting height of the lamps. For a certain ratio between the

spacing and the height of the lamps, a reflector can nearly always be selected which will furnish uniform illumination over the working surface. (These remarks concerning reflectors apply particularly to lamps of the tungsten type and to small gas units.)

Function of Reflector.—Owing to the direction of the light from the lamp, nearly all types of lamps, in addition to the downward light, furnish some rays which go upwards and away in other directions from the objects to be illuminated, and are therefore relatively not useful. Furthermore, a bright source in the field of vision causes an involuntary contraction of the pupil of the eye, which is equivalent to a decrease in illumination in so far as the eye is concerned. Hence, while reflectors or shades may at first seem to reduce the amount of light in the upper part of the room, their use actually increases the amount of light in a downward useful direction, and improves the "seeing" due to the better conditions which surround the eyes. The economic function of the reflector, as contrasted with the easier conditions it affords the eyes, is to intercept the otherwise useless or comparatively useless rays which do not ordinarily reach the work, and to reflect them in a useful direction. In performing this function, there is a choice through the design of the reflector, in the manner of distributing the light so as to make the illumination on the floor space uniform with certain spacing distances and mounting heights as previously mentioned.

Avoiding Dark Spots.—With the use of lamps for which a large variety or reflectors is available, the proper reflector should therefore be chosen so as to give the desired distribution of light. In other cases, as in the use of the gas or electric arc lamps, where the globe or reflector is usually a fixed part of the lamp, care must be exercised to space the lamps at sufficiently close intervals to insure uniformity of the illumination, that is, a freedom from the relatively dark spaces which exist between lamps when spaced too far apart.

Light Interiors.—With a light ceiling, the reflection of that part of the light which passes through a glass reflector to the ceiling, and which is added to the light thrown downward from the under surface of the reflector, is a factor in building up the intensity of the illumination on the working surface. *Great*

importance is therefore attached to light interior colors, especially on ceilings and the upper portions of walls, both in reinforcing the direct illumination, and in giving diffusion, which in turn adds to the amount of light received on the side of a piece of work. It should also be stated that the intensity of the light from bare overhead lamps when measured on the working surface may be increased by as much as 60 per cent. through the use of efficient reflectors. This is due to the utilization of the horizontal rays of light as previously stated, which predominate in the bare lamp, whereas the most effective light in factory and mill work is apt to be that which is directed downward.

Glass and Metal Reflectors Compared.—The question is sometimes raised as to the use of glass reflectors in connection with lamps for factory and mill lighting. This question is largely one of economy and maintenance, and it may be answered either in an off hand way or on a basis of practical experience with both types.

In large installations of small units there has been an effort to establish the merits of glass and of metal reflectors, by equipping lamps in adjacent bays with glass reflectors in one case and with metal reflectors in the other. It has been found almost invariably that if the choice is left to the workmen and superintendents, glass reflectors will be given preference over metal, mainly on account of the added cheerfulness they produce. If, therefore, the first cost and maintenance expense of the glass reflectors in practically the same as with metal, then glass may be employed to advantage.

Reflector Efficiency.—Glass reflectors on the market are capable of producing an amount of illumination equal and even greater in some cases than that produced by the best metal reflectors, and even if the first cost is somewhat higher, the added advantage of glass as opposed to metal is usually sufficient to make the small difference in cost a negligible item. This factor is all the more noticeable when one considers that the reflector itself is a small part of the total cost connected with the wiring or piping of the lamp and its reflector.

Pierced metal reflectors are also available. These are designed with small openings at the upper portion of the metal so that

the reflector may give the same distribution characteristics as a given glass reflector, thus affording a suitable metal reflector for use where glass may be objectionable. Some of the advantages of the pierced metal reflector are that it is unbreakable and that accumulations of dust on the outer surface do not decrease the efficiency. It is also true that the light which passes through the openings in this reflector to the ceiling cannot be diminished by dust on the outer surface as in the case of glass reflectors. (This type of reflector is shown in Fig. 8 under the main line shafting.)

Reflector Maintenance.—Regarding the maintenance of glass reflectors under rough factory and mill conditions, it may be stated that glass reflectors are used quite widely with almost a negligible increase due to breakage. Thus, out of the total maintenance cost in one representative installation, it was found that the charges were proportioned as follows:

Renewals, cost of lamps (tungsten)...........	75 per cent.
Renewals, broken glass reflectors..............	3 per cent.
Labor, making renewals and changing reflectors for washing	16 per cent.
Labor, reflector washing	2 per cent.
Additional indirect charges	4 per cent.
Total	100 per cent.

Points to Consider.—Reflectors will not be classified here from the commercial standpoint, but the following items should be given consideration in the selection of the type of reflector for factory or mill use:

1. Utilization efficiency: how much does the reflector contribute to the effective illumination on the work?

2. The effect in reducing glare.

3. Natural deterioration with age through accumulations of dust and dirt.

4. Ease in handling and uniformity of manufacture.

5. Physical strength and the absence of projections which may increase the breakage in case of glass reflectors.

A study of the various reflectors on the market with the aid of these items as a basis, will determine what reflectors are best adapted to given conditions. Regarding the third item in the foregoing list, it may be stated that under comparative tests in

service, the accumulations of dust and dirt on glass reflectors do not seem to be any greater than the coating of dirt which accumulates on the inside of a metal reflector in the same length of time.

Section XII. Side Light Important in Some Factory and Mill Operations.—It has been customary in many cases to measure the effectiveness of illumination in terms of the vertically downward component of the light. This method has ignored the value of side components in relation to vertical surfaces and openings in the side of the work. It is sometimes more necessary to light the side of the machine or the side of a piece of work than the horizontal surface. If, then, in designing a factory or mill lighting system, the prime object is the production of the greatest amount of downward illumination, it may happen that the side component is so small that the sides of machinery or of work are inadequately lighted.

Two Ways to Secure Side Light.—Experience indicates that there are two general ways in which to secure adequate side lighting. One of these methods is to lower the lamps, and the other is to use broader distributing reflectors than are called for by the rules which consider uniformity of the downward illumination only. Side walls or other reflecting surfaces will modify the results. Thus, after the determination of a certain type of reflector for producing uniform vertically downward illumination, it may be found that more side light is necessary, and this extra side component may, as stated, usually be secured by selecting a somewhat more distributing reflector. Broader distributing reflectors are apt to result in less downward illumination and will sometimes call for larger lamps than found necessary by preliminary calculations.

Practical Case.—As an illustration, in a certain lighting system a vertically downward intensity of about 3 foot-candles was deemed sufficient for the work involved. Measurements and observations showed that the side light was insufficient. In this particular installation it was found necessary to produce a vertically downward intensity of about 5 foot-candles on the average in order to secure an intensity of about 2 foot-candles on the side of the work, and also to use a somewhat broader distributing re-

flector than at first chosen. Two foot-candles on the sides of the work were sufficient in this case where bench work and work in the vise on small machine parts were conducted.

Keeping the Lamps High.—It is recommended that the lamps be mounted near the ceiling in all reasonable cases where side light is necessary, and that the side light be increased, ***not by lowering the lamps,*** but through the medium of broader distributing reflectors and larger lamps, if required. This attitude is taken on account of the glare which results when lamps are mounted too close to the work, a feature most noticeable in the absence of a reflector or where glass reflectors are used.

Section XIII. Maintenance.—The importance of system in the upkeep of natural and artificial lighting equipment may not appeal to every reader at the outset, but a consideration of the points involved will indicate that neglect of such work is apt to result in excessive losses of otherwise useful light.

Windows.—Factory and mill windows become covered in time with dirt, and produce greatly decreased values of natural light in consequence. These losses may easily be great enough to affect the workmen seriously, and to necessitate the use of artificial light at times when otherwise it would not be required. Dark surroudings also increase the likelihood of accidents. Regular window cleaning should therefore be a part of the routine of every factory and mill building or group of buildings.

Lamps.—Carbon filament, mercury-vapor, gas mantle and tungsten lamps burn out or break, globes and reflectors become soiled, and the various other items of deterioration take place so gradually that in many cases they are given no special concern in the practical economy of the shop. Moreover, it is hardly necessary to mention the fact that often lighting systems are allowed to deteriorate to an extreme point and nothing is done unless complaints come in from employees after the lighting facilities here and there throughout the shop have become so poor that work has to be discontinued temporarily. The losses of time from such circumstances, when added up throughout a year, are more than likely to exceed the expense of systematic attention to such maintenance items in advance.

Overhead System.—Furthermore, with modern methods where

the lamps are usually mounted overhead rather than close to each machine, the importance of relieving the workmen from any care of the lamps and placing it in the hands of a maintenance department is even greater than has been the case in the past particularly in large plants. To indicate the wisdom of a daily renewal of electric lamps, Fig. 24 has been worked up from the experiences in one large factory. In this factory all burned-out lamps are renewed each day except Saturday and Sunday, these renewals being based on a daily inspection of every lamp to ascertain whether or not it is in working condition.

Lamp Renewals.—A reference to the diagram shows that the renewals are considerably greater on Monday than on any other day of the week, this increase being due to renewals not given at-

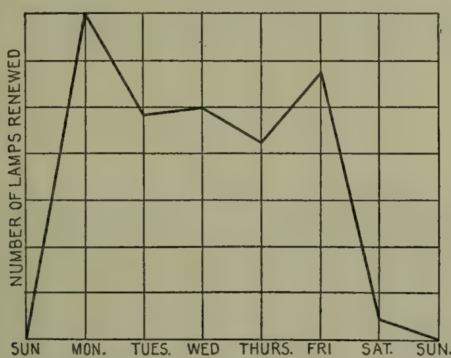


Fig. 24.—Fluctuations in daily lamp renewals.

tention on the two preceding days. Obviously, therefore, a continued neglect of the inspection and renewal of these lamps would soon result not only in inferior lighting conditions, but to large losses of time for the employees, not to speak of the annoyance involved.

Reflector Cleaning.—The serious loss of light when globes and reflectors are allowed to go for long periods without cleaning, is shown in Fig. 25. This set of curves resulted from a test on a glass reflector used with a tungsten lamp. The one curve shows the value of the light given by the lamp at different angles when the lamp and reflector are clean, while the smaller curve shows the enormous reduction of light after the lamp and reflector has been in service for about four months without being cleaned.

In this paricular case, which is a typical one, the loss of light at the end of the four month interval, amounted to about 50 per cent. The cost of electrical energy in this shop was such that the loss of light during the four months amounted to about 12 cents, while the total cost of taking down, washing and replacing this reflector amounted to about 3 cents. The economy of a fairly frequent attention to cleaning of such reflectors is at once apparent, even if the improved condition of the light in itself be ignored.

The examples just given, in the one case associated with the renewals of the lamps, in the other with the washing of the reflectors, will serve to illustrate the class of upkeep problems which

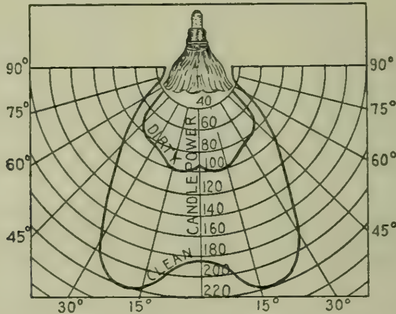


Fig. 25.—Curves showing serious losses of light from a tungsten lamp and its reflector due to accumulations of dirt. This is a condition applicable to all types of lamps, as other illuminants suffer corresponding losses from dirt accumulations.

are involved in shop lighting. The most forcible emphasis is applicable to the idea that system may properly be called a first step towards success in this line of maintenance work.

A Method of Inspection and Maintenance.—In one large factory a regularly developed method of inspection and renewals is employed. As an example, the method as applied to several thousand tungsten lamps, which are in service in the various buildings, will be described. All the lamps are inspected once per day, except Saturday and Sunday. A regular route is followed by the inspector, and all burned out lamps, broken switches, loose fuses, and similar items are noted. Careful observation is also made of reflectors which appear to need washing and any other points which might affect the efficiency of the

Fig. 26.—Very poor lighting in a worsted goods factory. The wiring is badly arranged, the contrasts between light and dark portions of the room are excessive, and in some cases the wrong size of lamp is used in a given reflector. The system is unsightly and represents bad practise. Compare with Fig. 27.

Fig. 27.—Worsted mill with localized general illumination. This is an example of excellent illumination with tungsten lamps and metal reflectors. Note the reflection from the goods to the ceiling. Compare with Fig. 26.

Fig. 28.—Very poor arrangement of arc lamps. The lamps are mounted to one side of aisle over line shafting. Very little light reaches the machinery to the right. Compare with Fig. 29.

Fig. 29.—Well planed system of arc lighting. The lamps are high and above the ordinary line of vision. Compare with Fig. 28.

system, after which a report is made up about noon and promptly sent to the maintenance department to permit all renewals and repairs to be made before night. In this manner the lamps are well maintained from day to day.

Marking Columns.—To facilitate this renewal work, it has been found advantageous to mark all columns through this shop. The inspector is thus enabled to indicate clearly the location of each burned out lamp and the renewal man to locate it without delay. It is helpful now and then in like manner to have the inspector note the unnecessary lamps found burning when artificial light is not required. If lamps are found burning at such times, a note sent to the head of the department calling attention to the matter is usually sufficient to remedy the difficulty.

Noting Soiled Reflectors.—As a check on a regular cleaning schedule, the inspector should note all reflectors in need of cleaning. The frequency of each cleaning will depend on the rate of deterioration due to the settlement of dirt on the surface of the glass or metal and also on the surface of lamps, and the fact should be kept in mind that the amount of dirt on a reflector is nearly always deceptive, that is, reflectors which have suffered a large deterioration in efficiency due to dirt often appear fairly clean, and for this reason it is best to increase the frequency of cleaning somewhat over that which seems sufficient from observation, particularly in view of the fact that tests indicate large reductions of light from apparently small accumulations of dust and dirt.

A Method of Washing.—In the factory just referred to, all reflectors are removed to a central washing point. Where the number of reflectors to be hauled is large, a truck is used. Often, however, where only a small number of reflectors is to be transported, small hand racks, devised for the purpose, are employed. When an installation is in need of washing, the scheme is to haul sufficient clean reflectors to the location in question. The soiled reflectors are then taken down and clean ones immediately put into place, after which the soiled reflectors are removed to the central washing point, washed and put into stock for the next location.

Section XIV. Expert Assistance Suggested.—The advantages of securing expert assistance in dealing with illumination is strongly emphasized. The points which come up for solution are complex and require, in many cases, the judgment of one who has had wide experience in the lighting field. In particular, anyone who undertakes to adopt any part or all of these suggestions will do well to secure the co-operation of a lighting expert capable of interpreting the legislative articles and of advising in a constructive manner.

Section XV. Other Features of Eye Protection.—Care is urged on the part of those responsible for the health and welfare of employees to see that adequate eye protection is afforded in all operations which are apt to cause injury to eyesight, if such protection is neglected. As typical of such other causes of danger to eyesight, arc welding may be mentioned, where the operator, according to accepted practise, must wear a helmet serving as an eye shield as well as a shield for the face and head in general. *Protective glasses for this purpose should not be judged as to their protective properties by mere visual inspection. They should, however, be analyzed for their spectral transmission of invisible radiation.* Protective measures should also be taken to prevent on-lookers from being unduly exposed to such eye dangers, by enclosing the welding operations with suitable partitions. These general remarks apply with equal force from the standpoint of those handling the operations to such other cases as the testing of arc lamps, inspection of hot metal and similar cases.

Section XVI. Auxiliary Systems for Safety.—The auxiliary system of lighting called for in Article XI of the Code, is a safety first precaution which is insisted upon in a large proportion of the 1,200 buildings coming under the control of the Bureau of Water Supply, Gas and Electricity in New York City, particularly such buildings as are occupied by large numbers of people. The same precaution is now observed by the Bell Telephone Company's offices fairly generally throughout the country, also by a large number of private manufacturers and by local ordinances compelling all types of amusement places to take this precaution.

Section XVII. Good and Bad Lighting Compared.—In order to give an idea of good and bad lighting, Figs. 13, 14, 26, 27, 28 and 29 are shown. These illustrations indicate the use of various types of lamps and a reference to the captions under the illustrations will bring out the weak points of the poorly lighted spaces, as well as the points of excellence in those cases which are designed in conformity with good illumination practise.

1915 REPORT OF THE COMMITTEE ON NOMENCLATURE AND STANDARDS OF THE ILLUMINATING ENGINEERING SOCIETY.*

DEFINITIONS.

Luminous flux is radiant power evaluated according to its capacity to produce the sensation of light.

The stimulus coefficient K_λ for radiation of a particular wav length is the ratio of the luminous flux to the radiant power producing it.

The mean value of the stimulus coefficient, K_m, over any range of wave-lengths, or for the whole visible spectrum of any source, is the ratio of the total luminous flux (in lumens) to the total radiant power (in ergs per second, but more commonly in watts).

The luminous intensity of a point source of light is the solid angular density of the luminous flux emitted by the source in the direction considered; or it is the flux per unit solid angle from that source.

Defining equation:

Let I be the intensity for the flux and ω the solid angle.

Then $$I = \frac{dF}{d\omega}$$

or, if the intensity is uniform,

$$I = \frac{F}{\omega},$$

Illumination, on a surface, is the luminous flux-density over that surface, or the flux per unit of intercepting area.

Defining equation:

Let E be the illumination and S the area of the intercepting surface.

Then $$E = \frac{dF}{dS},$$

or, when uniform,

$$E = \frac{F}{S},$$

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

The Illuminating Engineering Society is not responsible for the statements or opinions advanced by contributors.

Candle—the unit of luminous intensity maintained by the national laboratories of France, Great Britain, and the United States.[1]

Candlepower—luminous intensity expressed in candles.

Lumen—the unit of luminous flux, equal to the flux emitted in a unit solid angle (steradian) by a point source of one candlepower.[2]

Lux—a unit of illumination equal to one lumen per square meter. The C. G. S. unit of illumination is one lumen per square centimeter. For this unit Blondel has proposed the name "Phot." One millilumen per square centimeter (milliphot) is a practical derivative of the C. G. S. system. One foot-candle is one lumen per square foot and is equal to 1.0764 milliphots.

Exposure—the product of an illumination by the time. Blondel has proposed the name "phot-second" for the unit of exposure in the C. G. S. system.

Specific luminous radiation—the luminous flux-density emitted by a surface, or the flux emitted per unit of emissive area. It is expressed in lumens per square centimeter.

Defining equation:

Let E′ be the specific luminous radiation.

Then, for surfaces obeying Lambert's cosine law of emission.

$$E' = \pi b_0.$$

Brightness, b, of an element of a luminous surface from a given position, may be expressed in terms of the luminous intensity per unit area of the surface projected on a plane perpendicular to the line of sight, and including only a surface of dimensions negligibly small in comparison with the distance to the observer. It is measured in candles per square centimeter of the projected area.

Defining equation:

Let θ be the angle between the normal to the surface and the line of sight.

Then

$$= \frac{dI}{dS \cos \theta}.$$

[1] This unit, which is used also by many other countries, is frequently referred to as the international candle.

[2] A uniform source of one candle emits 4 π lumens.

Normal brightness, b_0, of an element of a surface (sometimes called specific luminous intensity) is the brightness taken in a direction normal to the surface.[3]

Defining equation:

$$b_0 = \frac{dI}{dS},$$

or, when uniform, $$b_0 = \frac{I}{S}.$$

Brightness may also be expressed in terms of the specific luminous radiation of an ideal surface of perfect diffusing qualities, *i. e.,* one obeying Lambert's cosine law.

Lambert—the C. G. S. unit of brightness, the brightness of a perfectly diffusing surface radiating or reflecting one lumen per square centimeter. This is equivalent to the brightness of a perfectly diffusing surface having a coefficient of reflection equal to unity and illuminated by one phot. For most purposes, the millilambert (0.001 lambert) is the preferable practical unit.

A perfectly diffusing surface emitting one lumen per square foot will have a brightness of 1.076 millilamberts.

Brightness expressed in candles per square centimeter may be reduced to lamberts by multiplying by $\pi = 3.14$.

Brightness expressed in candles per square inch may be reduced to foot-candle brightness by multiplying by the factor $144\pi = 452$.

Brightness expressed in candles per square inch may be reduced to lamberts by multiplying by $\pi/6.45 = 0.4868$.

In practise, no surface obeys exactly Lambert's cosine law of emission; hence the brightness of a surface in Lamberts is, in general, not numerically equal to its specific luminous radiation in lumens per square centimeter.

Defining equations:

$$L = \frac{dF}{dS}$$

or, when uniform,

$$L = \frac{F}{S}.$$

[3] In practise, the brightness b of a luminous surface or element thereof is observed, and not the normal brightness b_0. For surfaces for which the cosine law of emission holds, the quantities b and b_0 are equal.

Coefficient of reflection—the ratio of the total luminous flux reflected by a surface to the total luminous flux incident upon it. It is a simple numeric. The reflection from a surface may be regular, diffuse or mixed. In perfect regular reflection, all of the flux is reflected from the surface at an angle of reflection equal to the angle of incidence. In perfect diffuse reflection the flux is reflected from the surface in all directions in accordance with Lambert's cosine law. In most practical cases there is a superposition of regular and diffuse reflection.

Coefficient of regular reflection is the ratio of the luminous flux reflected regularly to the total incident flux.

Coefficient of diffuse reflection is the ratio of the luminous flux reflected diffusely to the total incident flux.

Defining equation:

Let m be the coefficient of reflection (regular or diffuse).

Then, for any given portion of the surface,

$$m = \frac{E'}{E}.$$

Lamp—a generic term for an artificial source of light.

Primary luminous standard—a recognized standard luminous source reproducible from specifications.

Representative luminous standard—a standard of luminous intensity adopted as the authoritative custodian of the accepted value of the unit.

Reference standard—a standard calibrated in terms of the unit from either a primary or representative standard and used for the calibration of working standards.

Working standard—any standardized luminous source for daily use in photometry.

Comparison lamp—a lamp of constant but not necessarily known candlepower against which a working standard and test lamps are successively compared in a photometer.

Test lamp, in a photometer—a lamp to be tested.

Performance curve—a curve representing the behavior of a lamp in any particular (candlepower, consumption, etc.) at different periods during its life.

Characteristic curve—a curve expressing a relation between

two variable properties of a luminous source, as candlepower and volts, candlepower and rate of fuel consumption, etc.

Horizontal distribution curve—a polar curve representing the luminous intensity of a lamp, or lighting unit, in a plane perpendicular to the axis of the unit, and with the unit at the origin.

Vertical distribution curve—a polar curve representing the luminous intensity of a lamp, or lighting unit, in a plane passing through the axis of the unit and with the unit at the origin. Unless otherwise specified, a vertical distribution curve is assumed to be an average vertical distribution curve, such as may in many cases be obtained by rotating the unit about its axis, and measuring the average intensities at the different elevations. It is recommended that in vertical distribution curves, angles of elevation shall be counted positively from the nadir as zero, to the zenith as 180°. In the case of incandescent lamps, it is assumed that the vertical distribution curve is taken with the tip downward.

Mean horizontal candlepower of a lamp—the average candlepower in the horizontal plane passing through the luminous center of the lamp.

It is here assumed that the lamp (or other light source) is mounted in the usual manner, or, as in the case of an incandescent lamp, with its axis of symmetry vertical.

Mean spherical candlepower of a lamp—the average candlepower of a lamp in all directions in space. It is equal to the total luminous flux of the lamp in lumens divided by 4π.

Mean hemispherical candlepower of a lamp (upper or lower)—the average candlepower of a lamp in the hemisphere considered. It is equal to the total luminous flux emitted by the lamp in that hemisphere divided by 2π.

Mean zonal candlepower of a lamp—the average candlepower of a lamp over the given zone. It is equal to the total luminous flux emitted by the lamp in that zone divided by the solid angle of the zone.

Spherical reduction factor of a lamp—the ratio of the mean spherical to the mean horizontal candlepower of the lamp.[4]

[4] In the case of a uniform point-source, this factor would be unity, and for a straight cylindrical filament obeying the cosine law it would be $\pi/4$.

Photometric tests in which the results are stated in candlepower should be made at such a distance from the source of light that the latter may be regarded as practically a point. Where tests are made in the measurement of lamps with reflectors, the results should always be given as "apparent candlepower" at the distance employed, which distance should always be specifically stated.

The output of all illuminants should be expressed in lumens.

Illuminants should be rated upon a lumen basis instead of a candlepower basis.

The specific output of electric lamps should be stated in terms of lumens per watt and the specific output of illuminants depending upon combustion should be stated in lumens per British thermal unit per hour. The use of the term "efficiency" in this connection should be discouraged.

When auxiliary devices are necessarily employed in circuit with a lamp, the input should be taken to include both that in the lamp and that in the auxiliary devices. For example, the watts lost in the ballast resistance of an arc lamp are properly chargeable to the lamp.

The specific consumption of an electric lamp is its watt consumption per lumen. "Watts per candle" is a term used commercially in connection with electric incandescent lamps, and denotes watts per mean horizontal candlepower.

Life tests—Electric incandescent lamps of a given type may be assumed to operate under comparable conditions only when their lumens per watt consumed are the same. Life test results, in order to be compared must be either conducted under, or reduced to, comparable conditions of operation.

In comparing different luminous sources, not only should their candlepower be compared, but also their relative form, brightness, distribution of illumination and character of light.

Lamp Accessories.—A **reflector** is an appliance the chief use of which is to redirect the luminous flux of a lamp in a desired direction or directions.

A **shade** is an appliance the chief use of which is to diminish or to interrupt the flux of a lamp in certain directions where such flux is not desirable. The function of a shade is commonly combined with that of a reflector.

A **globe** is an enclosing appliance of clear or diffusing material the chief use of which is either to protect the lamp or to diffuse its light.

PHOTOMETRIC UNITS AND ABBREVIATIONS.

Photometric quantity	Name of unit	Abbreviations, symbols and defining eqations
1. Luminous flux	Lumen	F. Ψ
2. Luminous intensity	Candle	$I = \frac{dF}{d\omega}, \Gamma = \frac{d\Psi}{d\omega}$, cp.
3. Illumination	Phot, foot-candles, lux	$E = \frac{dF}{dS} = \frac{I}{r^2} \cos \theta.\ \beta$
4. Exposure	Phot-second	Et
5. Brightness	Apparent candles per sq. cm. Apparent candles per sq. in.	$b = \frac{dI}{dS \cos \theta}$
	Lambert	$L = \frac{dF}{dS}$
6. Normal brightness	Candles per sq. cm. Candles per sq. in.	$b_0 = \frac{dI}{dS}$
7. Specific luminous radiation	Lumens per sq. cm. Lumens per sq. in.	$E' = \pi b_0,\ \beta'$
8. Coefficient of reflection	—	$m = \frac{E'}{E}$
9. Mean spherical candlepower		scp
10. Mean lower hemispherical candlepower		lcp
11. Mean upper hemispherical candlepower		ucp
12. Mean zonal candlepower		zcp

13. 1 lumen is emitted by 0.07958 spherical cp.
14. 1 spherical candlepower emits 12.57 lumens.
15. 1 lux = 1 lumen incident per square meter = 0.0001 phot = 0.1 milliphot.
16. 1 phot = 1 lumen incident per sq. cm. = 10,000 lux = 1000 milliphot.
17. 1 milliphot = 0.001 phot = 0.929 foot-candle.
18. 1 foot-candle = 1 lumen incident per square foot = 1.076 milliphot = 10.76 lux.
19. 1 lambert = 1 lumen emitted per square centimeter.*
20. 1 millilambert = 0.001 lambert.

21. 1 lumen, emitted, per square foot* = 1.076 millilambert.
22. 1 millilambert = 0.929 lumen, emitted, per square foot.*
23. 1 lambert = 0.3183 candle per sq. cm. = 2.054 candles per sq. in.
24. 1 candle per sq. cm. = 3.1416 lamberts.
25. 1 candle per sq. in. = 0.4868 lamberts = 486.8 millilamberts.

SYMBOLS.

In view of the fact that the symbols heretofore proposed by this committee conflict in some cases with symbols adopted for electric units by the International Electrotechnical Commission, it is proposed that where the possibility of any confusion exists in the use of electrical and photometrical symbols, an alternative system of symbols for photometrical quantities should be employed. These should be derived exclusively from the Greek alphabet, for instance:

Luminous intensity.. Γ
Luminous flux.. Ψ
Illumination.. β.

DISCUSSION.

Mr. F. A. Benford: I note in the text that the words "candle" and "candlepower" are used interchangeably. I wonder if Dr. Sharp will tell us if this Society has ever taken a stand as to preference in the use of the word "candle" or "candlepower?"

Mr. R. ff. Pierce: I should like to call attention to the possibility that the rating of lamps in the terms set forth on the sixth page might introduce some confusion commercially. It is recommended that the specific output of illuminants depending on combustion shall be stated in British thermal units per hour. In actual practise in the case of illuminants operated by gas, it has been demonstrated that the light output is practically independent of the calorific value of the gas. As the adoption of such a system of rating might conflict with or confuse commercial ratings, I should urge that it be offered in such a way as to make impossible any such confusion; it is not a practical way of rating commercially lamps of that type.

Mr. P. S. Millar: On the second page the committee defines the word "lux." I should like to ask if the committee wishes us to use that unit of illumination? It is used in Germany, based upon the Hefner. It is proposed here in connection with candle. If

* Perfect diffusion assumed.

the committee does not wish us to use the word "lux" in our work, I think it should not be featured so prominently in the report.

Most of the paragraph under lux is devoted to a discussion of the phot. If the committee wishes us to use the phot, I think it should be featured; it is given rather incidentally at the present time.

MR. J. R. CRAVATH: I believe I am correct that the new unit of brightness called the lambert is the first one to be distinctly originated within our Society through its Committee. I hope those who are working in brightness values will promptly adopt this new unit in publications relating to brightness.

DR. C. H. SHARP: Mr. President, the first question was, "Has the Society said anything on the subject of candle versus candle-power?" At the top of the second page of the report you will find this:

> **Candle, the unit of luminous intensity maintained by the national laboratories of France, Great Britain and the United States.**
>
> **Candlepower, luminous intensity expressed in candles.**

Mr. Pierce made some statement regarding the luminous output of gas lamps. He raised an objection to the rating of them in terms of British thermal units. That is a question the merits of which I am unable to go into. I would say, however, that the proposition which came to the committee first was that gas lamps should be rated in lumens per cubic foot per hour, but the prominent gas engineers on the committee preferred a rating in terms of lumens per British thermal units per hour, because the lumens were proportional to the British thermal units of the gas.

Mr. Millar has raised the question of the prominent featuring of the term "lux." I think his criticism is pretty well taken. My understanding of it has been that we have put in this tentative proposal of the word "phot," as made by Blondel, largely with the idea that it would form a basis eventually for a real. international unit of illumination. Now, the lux is unfortunately a kind of a bipartisan unit; so that perhaps the best thing under present conditions would be for us to drop lux entirely and to come out squarely and say we propose to use the phot and milliphot. The milliphot has a considerable advantage in being only 7 per cent. removed from the foot-candle, and we would understand illumination values in milliphots very readily on this account.

ARTIFICIAL LIGHTING OF TYPICAL OFFICES IN STATE, WAR, AND NAVY DEPARTMENT BUILDING.*

BY W. E. CHAPMAN.

Synopsis: This paper describes the old and new lighting conditions in the State, War, and Navy Department Building which was constructed in 1871-1886. Especial attention is given to the present-day lighting requirements in the building and the new system of general illumination by which they have been satisfactorily met. The colors used on the walls and ceilings of the rooms with the view to obtaining the maximum efficiency of tungsten filament incandescent lamps of about 1 watt per candle-power are also discussed; and it is shown that in the new system the energy consumption is 1 watt per square foot of floor space.

The State, War, and Navy Department Building at Washington, D. C., which was constructed during the period of 1871 to 1886, at a cost of upwards of $10,000,000, and whose combined floor space is upwards of ten acres, has since its completion been referred to as the largest and finest office building in the world. The architectural arrangement of its rooms for natural light and ventilation, as well as for convenience of access, is unexcelled to-day; but naturally enough the artificial lighting system originally installed, consisting at first of gas burners attached to large ornamental, solid brass chandeliers, and later a crude combination of both gas and electricity, was soon outstripped by the rapid developments in illuminating engineering.

There was one four-burner gas chandelier installed in the center of each room containing 400 square feet of floor space, which in general is the uniform size of all the office rooms. From the standpoint of beauty and uniformity this arrangement of the gas fixtures was splendid, but its impracticability was developed as soon as the rooms were occupied, and it was found on cloudy days, when artificial light was indispensable, that these fixtures furnished sufficient light only for those desks and files which were located directly under them and for a short radius from the center of the room. The great number of desks and files required by each of the three departments especially in rooms

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

occupied by the large clerical forces made necessary the placing of many desks and files at convenient intervals in all parts of the room. In the natural order of things the larger files, which were put in in rapidly increasing numbers, many of them extending from the floor to an 18 foot (5.48 m.) ceiling, were placed against the partition and the interior walls, where the light faded into insufficiency for practical purposes. Many desks and files were of necessity placed beyond the zone of sufficient illumination, so that on dark days the efficiency of the employees was considerably lowered, while some of the employees suffered from impaired eyesight.

To overcome these difficulties an electric lighting system was added throughout the building in 1887 and 1888; the arrangement of the lamps was governed by the location of the gas lights and desks and files, and therefore without any rule of uniformity. This installation, though void of beauty, proved to be practical, at least, for the time being; but as the business of the departments grew, increasing the personnel, desks, files, and such office appliances as the typewriter, adding machine, etc., the furniture and fixtures had to be rearranged in the rooms accordingly. Such rearrangement meant constant rearrangement of the electric lamps and later the installation of many desk lamps of different makes and of a variety of styles. Two to four electricians were kept busy most of the time making these changes and the rooms were soon filled with unsightly wires and old style rosettes and fixtures; the ceilings and walls were marred with plugs and broken plaster. Some of the units were in use, and as often as not many of them were out of service.

The desk lamp feature was particularly annoying and came to be known in the superintendent's office as the "desk lamp nuisance" not only in the matter of changes required by rearrangements of desks, etc., but because these lamps would often appear within the working vision of persons occupying desks in other parts of the rooms. Wires leading to them were also in the way and these and the other lamps, including gas chandeliers, became the lodging places for large quantities of dirt which, except in a few instances, was never removed.

Moreover, when the original electrical installation was made, a conically shaped metal reflector was used. These reflectors, of

course, prevented the rays of artificial lights from reaching the upper sections of file cases which, in almost all instances, are indexed on the outside of the box or drawer units that fill up their framework. Some means had to be provided to afford artificial light for these files and even the cumbersome wire-guarded portable lamp was furnished in many of the offices and file rooms, so that users of the files could see well enough to do their work.

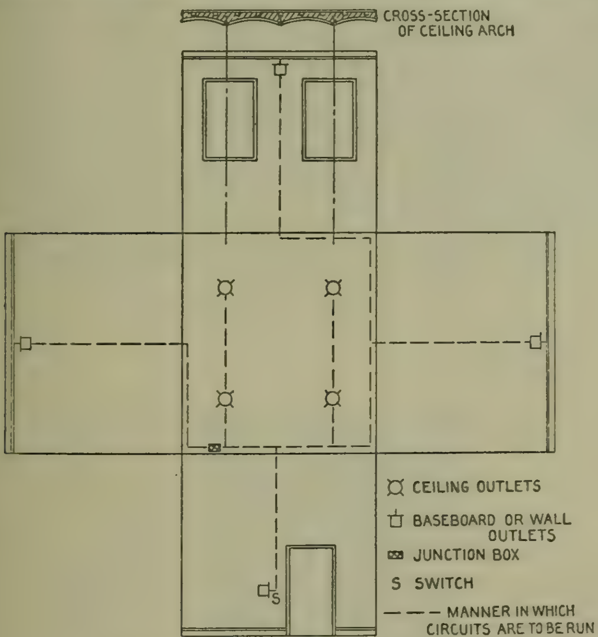


Fig. 1.—Plan of rewiring a typical room.

It became apparent that this chaotic condition had to be overcome by the installation of some general and uniform system of illumination, and with this end in view the superintendent of the building set about a careful and exhaustive study of the problem. In this study he sought and obtained the advice of some of the most celebrated illuminating engineers and experts of the country. He also consulted with a number of the larger manufacturers of modern fixtures, who furnished him with various samples representing their different styles and sizes of lighting units which he installed and tested under different conditions. In connection with the efficiency and adaptability of these units, he

studied the effects of the color of walls and ceilings on the artificial light and on the eye to determine what color scheme would serve best for use with both natural and artificial light from the standpoint of its being one that would harmonize with and be a proper reflector of light, and upon the principle that such a scheme must also afford the eye a restful relief when raised from the routine of office duty.

Particularly on account of the frequent criticism of the ventilation, especially during the winter months when doors and windows are closed and artificial lighting is most in use, the superintendent decided to use electric incandescent lamps throughout.

Photometric tests were made to ascertain the quantity of light required per square foot of floor, wall and ceiling space within the rooms with different color combinations and different sizes of lamps. These tests covered a period of about one year and certain rooms were wired and refinished in this scheme to ascertain its adaptability.

With the adopted scheme the walls were given a flat finish of buff, near cream, and the ceilings a finish of ivory white. The lighting was by means of tungsten filament incandescent lamps of about 1 watt per candlepower, selected and placed uniformly so as to give an energy consumption of 1 watt per square foot. The floor area of each room was divided into squares of about 100 square feet (9.29 sq. m.) each and a bowl-frosted lamp with a modern translucent, light opal reflector suspended over the center of each square at a height of 9 feet (2.7 m.) above the floor. (See Fig. 2.)

The frosted bowl prevented any direct rays of light from striking the eye through that portion of the lamp which was exposed at the bottom of the reflector. The reflector of course served to avoid glare from rays appearing through the clear portion of the lamp and, being of a high quality of illuminating glass, diffused the rays of light against the ceilings and the upper half of the walls. The ivory white ceilings and buff walls reflected a great portion of the upward light rays, establishing a special diffusion at the lighting units and a general diffusion at the walls and ceilings, particularly from the ceiling.

Fig. 2.—A typical small office occupied by clerks.

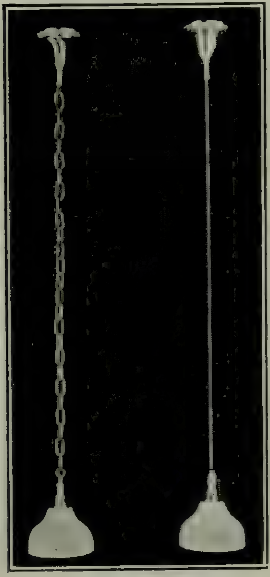


Fig. 3.—Standard fixtures used in building.

Fig. 4.—Seven four-unit rooms brought together by removal of partitions.

Fig. 5.—A drafting room with special spacing of fixtures.

The fixtures proper are of two kinds: solid brass chains in the principal office rooms and gold colored silk, duplex No. 16 Brown and Sharpe gauge lamp cord suspended from a brass egg and dart canopy which rests against the ceiling. Chain pull sockets were installed for individual control of the lamps with only chain enough to reach to within about one inch of the lower edge of the reflector. One switch to control all four lamps in each room was installed at a location convenient of access, usually near the door, one attachment plug being placed adjacent to the switch and all mounted with one brass cover flush with the wall,

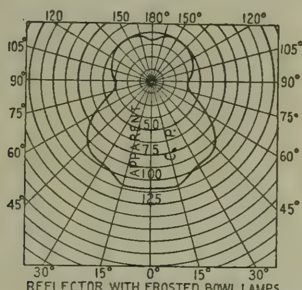


Fig. 6.—Photometric distribution curve of reflector with a frosted bowl lamp.

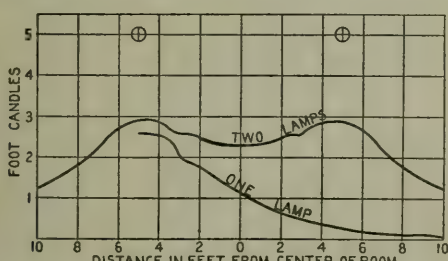


Fig. 7.—Illumination on a horizontal plane 6 ft. 6 in. below two 100-watt, bowl-frosted tungsten lamps with reflectors spaced 10 ft. apart.

where possible. The pull switches permit the two lamps nearest the windows to be turned off without disturbing the other two when the latter are needed in the darker part of the room.

The accompanying drawing, Fig. 1, shows how the lamps and the circuits to them as well as fan circuits are arranged in the rooms. Such a system of course reduces but does not eliminate distinct shadows, as it is readily apparent that the light reflected by the walls and ceiling and appearing from the respective units cannot be strong enough to prevent an object from casting

as many shadows as there are lamps in a room, the intensity of each shadow depending largely upon the relative position of the object from the various lamps.

These reduced shadows have been found to be of practically no no prejudicial consequences to any of our people except the draftsmen, and they have not had occasion to offer any serious complaint.

It would appear to be worthy of mention here also that in his efforts to arrive at a satisfactory system of general illumination, the superintendent sought to approach as nearly as possible a flat curve of illumination throughout all parts of the room, walls and ceilings included; and the wall and ceiling reflections in addition to the diffusion at the lamps go as far towards accomplishing such a result, perhaps, as could be by the use of exposed illuminating units.

To replace all the old objectionable special illumination with an efficient system of general illumination throughout the build-

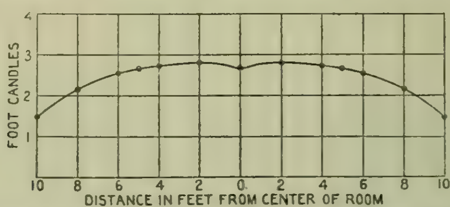


Fig. 8.—Illumination on a horizontal plane, 6 ft. 6 in. below 4,100-watt, bowl-frosted tungsten lamps, with translucent reflectors, spaced 10 ft. apart. Curve taken on a line through center of four-unit room, 2 ft. 6 in. above the floor, or at about the top of the ordinary desk.

ing was the one paramount thing to be accomplished, and it was the determination of the superintendent that this should be done. Many persons accustomed to the use of desk or individual drop lamps registered vigorous protests against their being compelled to use the general system, but once it was installed and the walls and ceilings changed from the old dark, light-absorbing blue to the more cheerful, light-reflecting buff and white, the value and practicability of the change was immediately appreciated.

The work of re-illuminating the entire building, except for a few special rooms, was commenced in November, 1914, and completed in February, 1915.

In practise so far the new scheme has produced eminently satisfactory results, and it is believed that it will meet all ordinary office requirements for a long time to come.

DISCUSSION.

MR. W. A. DURGIN: Figs. 7 and 8 show a maximum foot-candles intensity below 3. Does this represent the "new lamp and clean reflector" condition? With the marked increase in lamp efficiencies it would seem that our government should employ much higher intensities not only to secure higher output from the workers, but also to take position in the forward line of progress.

MR. W. E. CHAPMAN (In reply): Lighting conditions are such that during the daytime there is enough natural light in most of the rooms, except on cloudy days. It is not required that the artificial lighting units shall supply all of the light. They are merely auxiliary to the natural light. Persons working at night, however, find the artificial light adequate for all general purposes.

MR. G. S. BARROWS: This is a very interesting paper, but I cannot add much to the discussion except simply to agree with Mr. Durgin. I think we ought to be rather careful to note the difference between new and clean lamps and the average condition. Mr. Chapman's curves show a fair average condition; that was a point that was not quite clear to me, but that has just been explained.

MR. W. E. CHAPMAN: That was the condition.

MR. G. S. BARROWS: I don't understand from the paper that there has been any attempt to install indirect or semi-indirect lighting. I should like to know whether the architectural construction is such that it is inadvisable, or why some attempt was not made to install either of these systems.

MR. W. E. CHAPMAN: The reason is quite clear. We have a condition that would permit of semi-indirect or indirect lighting, but it was a question of funds. We were dependent upon the appropriation of Congress for making the improvements that were necessary; it was impossible to get sufficient money from Congress to make a better installation. We had, therefore, to do the next best thing and use the system outlined in my paper.

When the wiring in the State, War and Navy Department Building was installed in 1887 and 1888, the circuits were simply

run in wooden mouldings, which were exposed and altogether it was a very poor and hazardous installation; but in the new wiring process the circuits have been run in metallic conduits in all instances so that they are now thoroughly up to date throughout the building.

LIGHTING IN DOWNTOWN OFFICE BUILDINGS.*

BY ALFRED O. DICKER AND JAMES J. KIRK.

Synopsis: This paper contains data in tabular form concerning electric lighting service in certain office buildings in the downtown district of Chicago. The buildings were selected as typical examples of lighting installations made thirty, twenty-five, twenty, fourteen and six years ago; and one which was completed recently. Curves are given to show the relation between watts per square foot and foot-candles for the thirty years, and also the relation of cost per square foot per month for the various buildings. No attempt has been made in the paper to give a technical description of the present installations or to give recommendations for changes. The installations have been taken as they are and the description given.

The illuminating engineer is by nature attracted to the proposed building rather than to the older one which he passes in his everyday walks of life. He is desirous of having the lighting in the new building when completed typical of the best lighting practise, and in the age of "tear-down-the-old and build-a-new" he has found a large field. Nevertheless in the older buildings lies a much larger field of almost untouched harvest. In these, the older buildings, are thousands of workers toiling under lighting conditions typical of the first installations that were made. These lighting systems will soon be changed. They are so old now that either the wiring will be condemned by the various inspection departments, or else the tenants or owners will realize that for their own mercenary benefit more and better light must be provided for their employees.

The lighting of thirty years ago is as absurd to-day as the business policies of that period when applied to present-day business. It is also true that antiquated lighting installations are just as much a source of real loss as are antiquated business systems. Proper lighting is now generally considered an essential part of factory equipment and an essential item in the reduction of manufacturing cost; but at present it is not generally accepted among business men as an item in reducing

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

office costs. Data showing the reduction of office cost are difficult to obtain, but few engineers would dispute the statement that the working efficiency of a clerk or stenographer is reduced 25 per cent. after sundown in a poorly lighted office. This is the period of the day when the workers are tired and is therefore the period during which their comfort and efficiency should be considered.

One of the objects of this paper is to show the progress of lighting practise in downtown office buildings during the last thirty years, by taking as examples buildings typical of the periods during which they were built. For this purpose six buildings were chosen as follows:

Building	No.	1	built	30	years	ago
"	"	2	"	25	"	"
"	"	3	"	20	"	"
"	"	4	"	14	"	"
"	"	5	"	6	"	"
"	"	6	"	1	"	"

In all these buildings, even the most modern, are installations which the illuminating engineer would refuse to-day to accept as proper lighting; but nevertheless they are considered typical for the purpose of this paper.

It so happens that the oldest building chosen is one in which the owners had foresight enough at the time of its construction to wire for electricity. In the next two, in age, wiring was omitted at the time of construction but soon thereafter it was wired in exposed conduit or wooden moulding. In all three of these buildings the lighting is crude both from point of construction and resulting illumination. The installation has been made without thought or design—a drop cord installed over the desk or table where light was required. At this period electric light was expensive and the minimum amount was therefore utilized. A summary of the lighting of these three buildings is of little or no interest except as a comparative basis. The lighting is localized without reflectors in many cases and where reflectors are found a very cheap and inefficient one has been installed. The lighting is very inadequate. The original installation was of carbon lamps which have now been replaced by tungsten lamps, usually of 40 and 60-watt size. Cluster fixtures as a rule prevail—the most predominant type being a three or four-arm fixture

suspended on a rigid stem installed approximately 6 ft. 6 in. (1.98 m.) above floor. Wall switches were used occasionally, but as a rule key-sockets have been utilized. The esthetic considerations were not developed, but rather the lighting fixture was considered a necessary evil and not an ornament.

The next three buildings in chronological order show somewhat the effect of the illuminating engineer, at least it may be said that the lighting equipment has been given some attention. The fixtures are more efficient, more ornate, and general illumination has been introduced. The spacing shows a decided tendency away from localized lighting although in many of the offices, desk lamps have had to be relied upon. Particularly in these newer buildings the individual taste of the tenant as regards his lighting is evident, and so there are seen suites with semi-direct and indirect systems in all their variations.

The general building conditions are tabulated in Table I, which will answer at a glance many of the questions which might arise as to the details of the physical characteristics of the building and its lighting equipment. Its only value will be for purposes of comparison with Table II and a description of the lighting fixtures used. A continued advancement in fixture design, the tendency toward larger lamps and the deviation from localized lighting toward general illumination is seen in columns 6 to 16, with the addition in the newer buildings of semi-direct and indirect. It would be well to add here that even in the oldest building there exist installations of semi-direct and direct but these do not occur in sufficient numbers to change the typical lighting system of the building. It must be remembered that these buildings were not selected as examples of good lighting, but rather as buildings containing lighting installations typical of the age in which they were built.

Table II shows the total building light and power load together with such factors as influence the cost of such service. The connected load may be referred to Table I for reference to the size of the building.

The load-factor[1] varies from 6.34 per cent., or 1.52 hours, to

[1] Load-factor, as used in this paper, may be described as follows: The ratio of actual monthly meter consumption (Kw-h.) to continuous use of maximum demand, or

$$\frac{\text{Kw-h. (consumption)}}{720 \times \text{Kw-h. (maximum)}}$$

TABLE I.—DESCRIPTION OF BUILDINGS.

Bldg.	Age	Size in feet	Floor space (sq. ft.)	Height of bldg. floors (feet)	Lighting fixture					Wiring	
					Suspension	Lamps per fixture	Lamp position	Type of lamp	System	Conduit	Moulding
1	2	3	4	5	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1	30	80 x 100	81,600	12	3.5 ft. stem	2	Vertical and angle	60-watt	Direct	Concealed	Exposed
2	25	80 x 115	110,400	12	3.5 ft. drop cord	1	Vertical	40 and 60-watt	Direct	Exposed	Exposed
3	20	190 x 141	340,000	17	3 ft. stem	3 and 4	Vertical	60-watt	Direct	Exposed and concealed	Exposed
4	14	120 x 144	204,000	17	3 ft. chain	1	Vertical	100-watt	Semi-direct	Concealed	None
5	6	52 x 110	95,000	18	Ceiling	4[1]	Vertical	60-watt	Indirect Semi-direct Direct	Concealed	None
6	1	96 x 163	106,836	18	Ceiling	1	Vertical	100-watt	Indirect Semi-direct Direct	Concealed	None

[1] This is not general practise but is an exception in a building of this class.

TABLE I.—DESCRIPTION OF BUILDINGS.—(*Continued.*)

Bldg.	Age	Size in feet	Floor space (sq. ft.)	Height of bldg. floors (feet)	Typical office space				Typical corridor				Exterior lighting
					Size in feet	Ceiling height	Decoration (walls and ceiling)	Professional or commercial	Size in feet	Spacing of units	Fixture	Hanging height	
1	2	3	4	5	13	14	15	16	17	18	19	20	21
1	30	80 x 100	81,600	12	15 x 22	10′ 6″	Brown and white	Professional	6 x 100	21′	40-watt prism glass	Ceiling	None
2	25	80 x 115	110,400	12	20 x 30	10′	Cream and white	Commercial	6 x 60	15′	40-watt opal glass reflector	Ceiling	None
3	20	190 x 141	340,000	17	20 x 20	10′ 6″	Cream and white	Professional and commercial	8 x 500	21′	40-watt opal ball	Ceiling	None
4	14	120 x 144	204,000	17	20 x 20	10′ 6″	Cream and white	Commercial	12 x 36	18′	40-watt opal ball	Ceiling	None
5	6	52 x 110	95,000	18	15 x 25	10′ 6″	Cream and white	Commercial	8 x 80	21′ 6″	40-watt opal ball	Ceiling	None
6	1	96 x 163	106,836	18	18 x 33	11′ 6″[1]	Cream and white	Commercial	9 x 174	15′	40-watt prism glass	Ceiling	None

[1] This is not general practise but is an exception in a building of this class.

17.48 per cent., or 4.2 hours use of maximum demand. The minimum may be explained by the fact that this building is one in which the lighting was installed after the building was completed and the installation was very inadequate. The maximum load-factor occurs in a newspaper building of such design that many of the lights burn of necessity most of the day.

The rates for electric service upon which is based the "average net bill per month" is as follows: the building owner buys the electric service for light and power either on a wholesale contract, if the building is of sufficient size, or on separate contracts for light and power. In either case in the buildings chosen for discussion in this paper the tenants are individual customers of the Commonwealth Edison Company. In the determination of the item of cost, the ratio of maximum demand to connected load is a prominent factor and for this reason it is here included.

TABLE II-A.—COMPARATIVE LIGHTING DATA.

Bldg.	Age	Total building light and power					
		Connected load Kw.	Per cent. load-factor	Av. Kw-h. per month	Av. max. per month	Av. net bill per month	Ratio max. connected load per cent.
1	2	3	4	5	6	7	8
1	30	100.108	10.45	7,535.8	70.0	$ 388.37	70
2	25	159.210	6.34	7,212.9	63.3	357.52	39
3	20	380.124	7.33	20,062.7	232.4	1,008.75	61
4	14	877.823	17.48	110,486.4	424.2	2,347.20	48
5	6	199.089	13.03	18,241.1	134.4	745.47	67
6	1	342.790	6.38	15,978.7	96.0	610.82	28

TABLE II-B.—COMPARATIVE LIGHTING DATA.

Bldg.	Elevators and Public Lights						
	Elevators	Connected load Kw.	Per cent. load-factor	Av. Kw-h. per month	Av. max. Kw. per month	Av. net bill per month	Ratio of max. to connected load
	9	10	11	12	13	14	15
1	5 hyd.	4.500	30.91	1,001.5	3.961	$ 40.74	88
2	2 elec.	78.250	8.25	4,626.0	50.700	183.74	64
3	12 elec.	41.472	17.42	5,201.5	16.165	185.23	38
4	8 hyd.	688.602	19.88	98,553.6	311.666	1,753.31	45
5	6 elec.	70.870	23.11	12,007.5	68.625	403.37	96
6	8 elec.	220.090	6.71	10,789.3	45.000	338.12	20

Similarly the second portion contains data on elevators and public lamps.

This table contains a separation of Table II-A showing the same data on that part of the total service which is used for elevators and public lamps.[2]

The percentage of this portion of the electric consumption to the total building consumption is shown below:

Building	Per cent.
No. 1	13.3
No. 2	64.1
No. 3	25.9
No. 4[3]	89.1
No. 5	65.8
No. 6	67.5

or an average of 39.3 per cent. for all of the buildings (excluding No. 4).

TABLE II-C.—COMPARATIVE LIGHTING DATA.

Bldg.	Offices						
	Connected load Kw.	Load-factor	Number offices occupied	Av. Kw-h. per office per month	Av. max. per office per month	Av. net bill per office per month	Ratio of max. to connected load
	16	17	18	19	20	21	22
1	73.748	6.76	88	40.6	0.632	$2.62	75
2	80.960	4.64	80	32.3	0.684	2.17	64
3	307.242	5.22	305	37.8	0.667	2.24	66
4	151.683	6.16	73	92.1	1.218	4.97	58
5	112.900	4.70	60	64.8	0.936	4.09	49
6	53.901	2.43	31	95.6	1.32	5.82	76

Here are displayed the same conditions applied to the office or rentable area of the building. This portion represents 17.0 per cent. of the total building consumption. The tenant's load-factor is extremely low, showing a use of the demand of from one half to one and one half hours per day. The minimum load-factor occurs in the newest building. This is due to the fact that the building occupies a small land area with good exposure facing Lake Michigan, and it is higher than the surround-

[2] Public lamps include all lighting contained in or around building which is not chargeable to tenants' meters, *i. e.*, corridors, exterior lighting, toilets, etc. Elevators include all electricity used for power purposes.

[3] This includes power for printing presses and is therefore not typical for this class of building.

ing buildings. The conditions make daytime burning of lamps unnecessary in many of the offices.

TABLE II-D.—COMPARATIVE LIGHTING DATA.

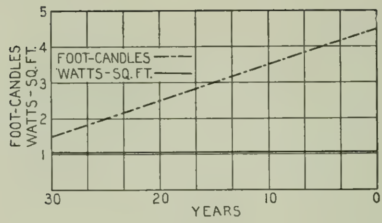
Bldg.	Store space					
	Connected load Kw.	Load-factor	Av. Kw-h. per month	Av. max. Kw. per month	Av. net bill per month	Ratio of max. to connected load per cent.
	23	24	25	26	27	28
1	21.860	18.78	2,955.7	10.4	$116.63	47
2	80.960	4.64	32.3	0.68	2.17	67
3	31.410	14.62	3,307.0	12.6	137.40	40
4	37.538	19.25	6,203.3	23.6	230.45	63
5	15.311	20.97	2,343.2	9.6	96.41	63
6	68.899	4.32	2,223.2	10.1	92.15	14

Inasmuch as the store and shop areas on the first and second floors represent a load-factor of considerably higher value than the office space, a further separation has been made. In this table the load used by the store or shop is analyzed. This portion represents 9.5 per cent. of the total building consumption. It will be noted that the average load-factor of this portion of the building is 13.76 per cent. (3.3 hours) as against 4.99 per cent. (1.2 hours) for the office portion, and the ratio of maximum demand to connected load is 49.3 per cent. for this portion as against 73.3 per cent. for the office portion, which shows the store to be the longer-hour user, while the office uses a higher proportion of the connected load for a very short time. The former load is by far the most desirable one from the central-station point of view. The fact that the office uses the lamps for such a short period is probably the reason that the office is the most dilatory in considering lighting improvement; but, as already stated, the time that the office requires light—short though it may be—is the very time that light is most essential.

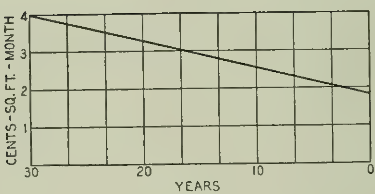
Table II-E sums up all the lighting data which have preceded. It will be noted that during the thirty years there has been little change in the watts per square foot provided, while the intensity has increased with each period and the cost per square foot has decreased. It must be borne in mind that the reason for the fact that the provided load has not increased during this thirty-

Fig. 1.—An installation in the oldest office building.

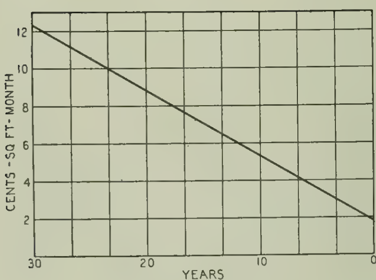
Fig. 2.—An installation in the newest building.



Curve 1.



Curve 2.



Curve 3.

year period is because the older buildings were not provided with what is to-day called sufficient illumination, together with the increased efficiency of illuminants. The standards of to-day are greatly in excess of those of previous years. These relations are shown graphically in curves 1 and 2.

TABLE II-E.—COMPARATIVE LIGHTING DATA.

Bldg.	Watts per sq. ft.	Intensity foot-candles	Cost of light per sq. ft. per month
1	29	30	31
1	1.02	1.5	$0.042
2	0.75	2.0	0.018
3	1.09	3.0	0.031
4	1.24	3.5	0.029
5	0.94	4.0	0.025
6	1.02	4.5	0.016

Curve 1 shows the increased intensity of illumination with practically the same provided load.

Curve 2 shows the reduction in cost of electric light due to increased efficiency of illuminants and fixtures. Curve 3 shows the reduction in cost due to increased efficiency of illuminant, fixtures and reduction in rates for lighting.

Table III shows data on the office portion of the first four buildings using carbon lamps as was the case when the lighting systems were installed. In this table the rating of the lamp is five watts per candle. The cost data are shown graphically on curve 3.

TABLE III.—CARBON LAMP.

Offices.

Bldg.	Connected load Kw.	Per cent. ratio of max. to connected load	Per cent. load-factor	Average Kw-h. per office per month	Average net bill per month per office	Cost in cents per sq. ft. per month
1	368.740	75.48	6.764	203.325	$13.12	3.975
2	404.800	67.18	4.64	161.650	10.86	1.810
3	1,536.210	66.282	5.223	189.400	11.24	2.810
4	758.415	58.607	6.162	460.915	24.89	6.220

Progress during these thirty years may be very forcefully shown

by a comparison of the two photographs. The first one is of an original installation in the oldest building and the second of the newest installation in the newest building. These two pictures indicate two extremes: one is merely a method of supporting the light source, the other an efficient ornate lighting fixture.

DISCUSSION.

Mr. G. H. Stickney: There are a few classes of workers who are subjected to more severe eye-strain than office employees. Casual observation will show many examples of inadequate and glaring illumination. It is to be hoped, therefore, that the excellent papers dealing with this subject will be influential in bettering conditions.

Owing to the crowding of buildings in our large cities, artificial lighting is used to supplement daylight fully as much as for night work. When used in the daytime a higher intensity is demanded than for night work. On the other hand glare effect is less serious. I have in mind an office illuminated by direct lighting which in the evening appears glary and somewhat overlighted, but in the dusk, which represents the period of maximum use, the lighting is unusually good. I mention this to bring out the point that an installation often has two distinct requirements to meet which may necessitate a compromise in the design. In general it is apparent that the practise in office lighting is tending strongly toward the use of the semi-indirect and indirect types of equipment and with this is coming a considerable improvement in the standard of office lighting.

Mr. G. S. Barrows: This paper states: "It so happens that the oldest building chosen is one in which the owners had foresight enough at the time of its construction to wire for electricity." That building has been built about 30 years and I wonder if the wiring put in at that time will meet with the approval of the underwriters. I should like to ask the authors if they found it necessary to change the wiring in this building. I think that is a point that possibly is being lost sight of in an attempt to simply provide for proper illumination. It seems to me that it is most desirable for us to impress on architects and builders the

necessity of providing for proper wiring and also gas piping in all buildings that are being erected. There is no telling what the developments may be in the future and provision should be made for the use of either form of energy. The cost of providing for either electric wiring of any kind, that is, providing for wiring that may be done at some future time, in accordance with some future ruling of the underwriters, or the installation of gas piping is but a very small fraction of a per cent. of the total cost of the building; whereas after the building is erected, the proper wiring or piping may amount to a very large per cent. of the total cost of the building. Beyond the simple use of energy for light there is no telling what the developments may be for the use of energy for some other purpose, for heating or we don't know what, and so I think that as illuminating engineers, or as engineers, I should say, we ought to go a little further than simply taking care of the illumination at the present time. We ought to impress on the architects and builders to provide, as far as they can, for all future demands. That question has been, and is being, pretty carefully studied by a good many people at the present time and I think we should provide for supplying in the future energy for almost any purpose.

Mr. James J. Kirk: I might say a few words in regard to the wiring conditions of the building that was built 30 years ago. At the time this building was completed it was inspected and was passed by the City Inspection Department. Since that time it has been reinspected for defective wiring. Wiring for new installations have also been made in accordance with the latest rules of the Department of Gas and Electricity.

PILOT FLAME IGNITION OF INCANDESCENT GAS LAMPS.*

BY C. W. JORDAN.

Synopsis: Despite the fact that many ingenious mechanisms have been devised for securing automatic distance ignition of gas lamps, the simple by-pass pilot flame remains as the most positive, serviceable and economical. A description of various types of pilot tips and by-passes is given, together with illustrations of the most successful types. The troubles which are often encountered in service are enumerated, as well as means which have been devised for their elimination. The application of a new type of pilot in giving ample general illumination to distinguish objects in rooms at night is described in detail.

INTRODUCTION.

The subject of pilot flame ignition of incandescent gas lamps may appear to many to be rather a minor or unimportant detail of the broad general subject of gas lighting, and yet on analysis it will be found to be extremely vital for the successful operation of lamps in practise.

Convenience in gas lighting has become a necessity and many devices have been perfected for securing automatic ignition, in some cases controlled from distant points.[1,2]

Despite the ingenuity shown in the design and mechanical construction of these devices, for one reason or another they have not recommended themselves as competent to meet the practical requirements of service.

Those which are apparently satisfactory automatically actuate a mechanism, turning on the main gas supply which in turn is ignited by means of a pilot flame. Therefore the convenience of such mechanical devices is dependent not only upon their own merits, but also upon that of the pilot.

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

[1] Gilpin, F. H., Automatic and Distant Lighters; *Proceedings A. G. I.*, vol VIII, 1913, Part II.

[2] Jordan, C.W., Recent Advances in Indoor Gas Lighting; TRANS. I. E. S., vol. IX, 1914.

Other devices, which do not use pilots, while ingenious, well constructed and positive in action, owing to their high initial cost do not find wide application.

Pyrophoric igniters, self-lighting mantles, etc., are not extensively used because of the ease with which the mechanical parts get out of order or on account of the short life of the active material.

The simple pilot by-pass and gas cock actuated by pulling a chain meet the demand for convenience, economy and service in the most satisfactory manner.

This paper, therefore, will be devoted to telling the history of the use and improvement of this simple means of ignition, which depends upon the same energy or fuel that supplies the lamp itself, and which is operated by the same mechanical movement that controls the lamp. Every consideration points to this as the ideal as well as common sense method of ignition, if it can be perfected.

PILOT BY-PASSES.

The term pilot by-pass may be defined as a device by means of which a supply of gas is regulated and led from a point just ahead of the gas cock of a lamp to a pilot tip or point of discharge conveniently placed near the mantle.

The gas cock and pilot take-off are in some cases of separate construction from the lamp and easily detachable, while in others they constitute a true part of the lamp construction.

The length of the pilot flame is regulated by turning a small screw which moves in or out of a constriction in the passageway leading to the pilot tip.

In some instances lamps are equipped with so-called "flash pilots." A flash pilot may be defined as one in which the pilot momentarily elongates during ignition and shoots across the top of or into one or more mantles of the lamp. The means for successfully accomplishing this are several.

In one lamp a secondary cock is connected to the primary gas cock so that upon pulling the chain to light the lamp it is turned 180° and the gas passes through to the pilot tip at unrestricted pressure, by-passing the ordinary regulating screw.

Another device consists of an additional passageway bored in

the gas cock, which on being turned on supplies gas at unrestricted pressure through a small tube by-passing the regulating screw. When the cock is turned on full the passageway in the gas cock is no longer opposite the passageway leading around the regulating screw and the gas to the pilot is supplied only through the usual regulating screw.

Flash pilots are effective, especially in arc lamps, in that they secure more positive and softer ignition of all the mantles.

PILOT TIPS.

Little trouble has been experienced in constructing efficient means for regulating and conveying the pilot gas supply to the point of discharge, but the construction of a satisfactory pilot tip, especially for inverted lamps, has been very difficult.

The main troubles encountered are (1) carbon formation, (2) clogging of the tip, due to disintegration of the gas, etc., and (3) the ease of extinguishing the flame by draughts.

With upright lamps a plain metal tube of small diameter, placed properly in a vertical position, burns satisfactorily, but the flame is easily extinguished if the lamp is subjected to excessive draughts.

A center pilot was then designed which consists, briefly, of placing the pilot flame directly above and in the center of the burner cap gauze, thus utilizing the mantle as a means of effectively protecting the flame from draught. The construction of a center pilot by-pass is shown in Fig. 1.

With inverted lamps it was necessary to use pilot tips made of lava or other refractory material in order to overcome the common troubles before mentioned.

Lava pilot tips have undergone decided changes, both in the principle upon which they operate and in design. The first type consisted of a simple passage, drilled through the tube and having a side outlet for discharging a luminous flame horizontally. A pilot tip was then developed which gives a blue Bunsen flame while burning. The gas discharges horizontally through a small orifice into a mixing tube provided with two air inlets. When operating at normal consumptions, between 0.1 and 0.15 cu. ft. per hour, a perfect Bunsen flame is obtained which is extinguished by draught with far greater difficulty than the luminous flame

pilot and has the additional advantage of eliminating troublesome carbon formation or smoky flame. Changing the position of the primary air inlets from a vertical to a horizontal position was found to render the pilot appreciably more resistant to draughts. Six types of lava tips are shown in Fig. 2.

In the early development of the Bunsen flame pilot a series of unlooked-for defects were found, a description of which may be of interest. In order to obtain a true Bunsen flame it is necessary to make the orifice of very small diameter, 0.016 in. (0.40 mm.). After several hundred hours burning of the lamp the orifices invariably become clogged. The tips were made of natural lava,

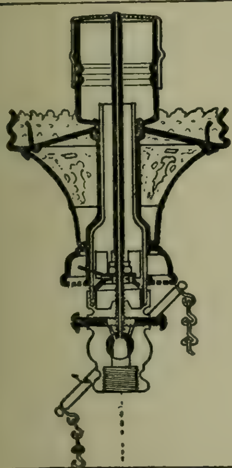


Fig. 1.—Center pilot burner.

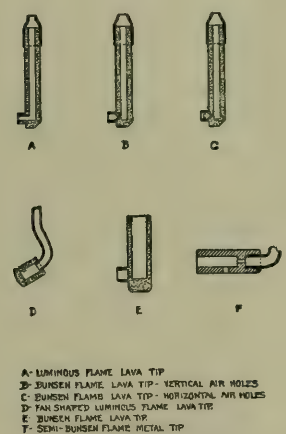


Fig. 2.

baked, and on the interior a hard glossy coating of carbon, resembling flaked graphite, was found. This extended through the entire passageway to the orifice which, on account of its small diameter, became stopped first. An investigation was made and it was found that the decomposition of the hydrocarbons in the gas to carbon was influenced not only by the high local temperature (620° C. at the orifice), but also by the physical properties of the substance used in construction. By using a tip made of finely crushed natural lava, repressed and baked, the trouble was practically eliminated. A small amount of carbon formed in the passageways, which was grayish instead of black, and after the

lamps were burned several thousand hours was found not to give trouble.

An interesting series of experiments was made, the results of which clearly illustrate the influence of the physical and chemical properties of the pilot tip material upon the decomposition of the gas. Various substances were placed in a transparent quartz tube, through which illuminating gas was passed, and heated

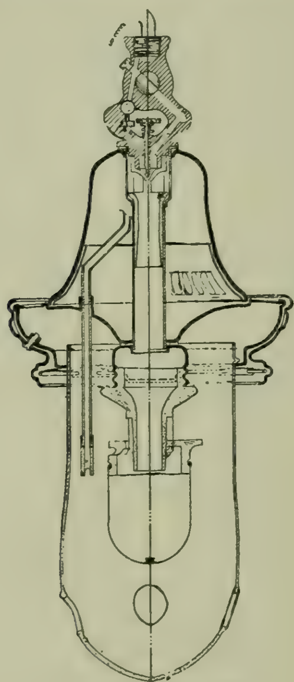


Fig. 3.

slowly and uniformly by means of an electric furnace. Certain substances, like metallic oxides (particularly mantle ash) became covered with carbon at a temperature as low as 260° C., while others, like glass, quartz, etc., only darkened at a temperature of above 650° C.

A still more recent change has occurred both in the design of pilot tips and in the position in which they burn. The pilot tip of the lamp shown in Fig. 3 is mounted vertically and in this

position the flame is very well protected from draughts and at the same time is positive in its ignition of the mantle.

The advantages of this type of tip are (1) that there is no orifice which may become clogged with carbon from the decomposition of gas, (2) in case the pilot flame becomes overadjusted there is no danger of cracking the enclosing glass cylinder, and (3) that when subjected to excessive draught the pilot flame retreats within the pilot tip and is effectively protected.

SERVICE TROUBLES.

Pilot devices are subject to numerous troubles in service. In certain localities the methods of manufacturing and purifying gas are liable to change suddenly from normal and often tar particles are carried in suspension by the gas for considerable distances from the works. In this event the tar rapidly accumulates on the pilot adjusting needles of the lamps and completely closes the minute annular opening through which the gas discharges. In order to overcome this trouble a purifying device, shown in Fig. 4, was designed. Essentially it consists of passing the gas through a small cylindrical brass tube which has been packed with asbestos wool, glass wool, mineral wool or other suitable material. The gas to the pilot flame is completely detarred by this method for a long period. When the filtering material becomes clogged or saturated, the brass tube is removed, cleaned and repacked. This simple device has proven to be very effective and in a few instances absolutely essential for the proper working of pilots.

Pilot outage due to draughts is a condition which lamp manufacturers have been attempting to minimize and eliminate. The seriousness of this trouble is primarily dependent upon the conditions under which the lamp burns and whether it is an indoor or outdoor lamp.

The luminous flame pilot is far from desirable in this respect, unless it is properly surrounded by a protecting casing in which case it is very liable to carbonize. With upright lamps the pilots can be readily enclosed by the mantle (see Fig. 1) and are thus very efficiently protected.

In the case of inverted lamps the problem was more difficult. Investigation led to the adoption of the Bunsen flame pilot tip

and finally in a later modification to a type which is very difficult to extinguish (see Fig. 3).

With outdoor lamps the use of semi-Bunsen pilots, surrounded by a protecting casing (see Fig. 5), has proven very satisfactory.

Radical changes in the construction of pilot tips, being experimented with at present, give promise of producing a practically inextinguishable pilot in the near future.

PILOT CONSUMPTION.

A consideration of the consumption of gas by pilots is of importance in that consumers are often badly misinformed or entirely ignorant of its magnitude. The consumption is not only influenced by the length of flame which is judged adequate by the adjuster, but also upon the particular type of pilot by-pass used.

The so-called "sub-flame" pilot by-pass is in reality a simple device for turning low a gas lamp. As the flame must burn over the entire surface of the burner gauze without danger of flash-back, the consumption is naturally greater than that of an ordinary pilot.

The use of the "sub-flame" pilot by-pass is rather limited and the pilot consumption should not be taken as representative of the more efficient types.

The following table shows the normal consumptions of various types of indoor and outdoor lamps and the ratios of the total gas consumption to that of the pilot consumption.

Lamp	Normal pilot cons. per hour (Cu. ft.)	Approx. length of flame (Inches)	Pilot cons. per year (Cu. ft.)	Normal lamp cons. per hour (Cu. ft.)	Lamp cons. per year 4 hrs. daily (Cu. ft.)	Pilot cons. per cent. of total cons.
1 burner inverted indoor, Bunsen pilot	0.120	¼	1051.2	3.50	5,110	17.1
1 burner upright indoor, luminous pilot	0.095	¼	832.2	4.65	6,789	10.9
3 burner inverted indoor arc, semi-Bunsen pilot	0.147	⅜	1287.7	10.00	14,600	8.1
5 burner inverted outdoor arc, semi-Bunsen pilot	0.213	½	1865.9	17.50	25,550	6.8
1 burner inverted outdoor, luminous pilot	0.152	⅜	1331.5	3.45	5,037	20.9

These calculations are made on the assumption that the lamps

operate on mixed gas at 2.5 in. (63.5 mm.) pressure. Total heat value 650 B. t. u. per cu. ft.; specific gravity 0.660.

NOVEL USE OF BLUE FLAME PILOTS.

As mentioned before, the essential reasons for changing from the luminous flame to the non-luminous Bunsen flame pilot were because of the greater difficulty of extinguishing the flame of the latter by draughts and the elimination of troublesome carbon formation or smoky flames.

In addition to these features the non-luminous flame lends itself to a novel and efficient use. It has long been contended that the luminous flame pilot instead of being considered a necessary expensive accessory of a gas lamp is in reality an efficient adjunct, in that it serves the purpose of guidance to the consumer desiring in turning on a lamp in a dark room.[3] By placing the Bunsen flame pilot so as to impinge to the extent desired upon the mantle an increase in the intensity of light of over five times that of the luminous flame pilot is obtained.

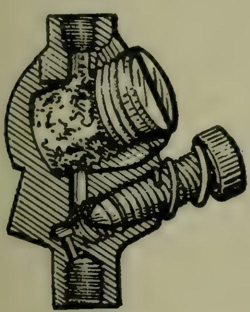


Fig. 4.—Tar scrubber.

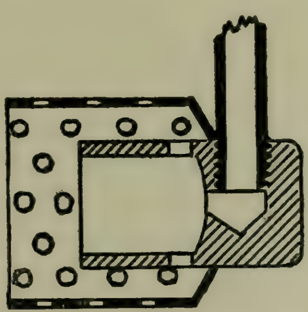


Fig. 5.—Semi-Bunsen protected pilot.

The following table shows the maximum horizontal candlepower obtained from the two types of pilot flames:

Type flame	Max. horizontal candlepower	Corr. cons. cu. ft. hour	Hor. candlepower per cu. ft.
Bunsen flame	0.1612	0.126	1.28
Luminous flame	0.0319	0.130	0.245

Open flame candlepower of gas burned in 8 ft. tip 22.0 at a 5 ft. rate.

Litle, T. J., Convenience of Gas Lighting, TRANS. I. E. S., vol. IV, 1909.

The increase in intensity not only serves as a better guidance in turning on the lamps at night, but to the dark adapted eyes it affords sufficient illumination to comfortably distinguish many objects in an ordinary living room. This is obtained at a cost no greater than that of maintaining the luminous pilot flame. In addition it is more difficult to extinguish the flame of a pilot impinging on the mantle.

In cases where pilot illumination would be objectionable, it is merely necessary to turn the pilot flame aside from the mantles and practically no light is obtained.

PHYSICAL LABORATORY,
THE UNITED GAS IMPROVEMENT CO.,
Philadelphia, Pa.
Sept. 3, 1915.

DISCUSSION.

MR. F. A. VAUGHN: I am particularly interested in the pilot light and the automatic lighter and extinguisher for street lighting gas lamps and if there is any one in the room who could give me any information on this particular application of the pilot, I would be very glad.

MR. T. J. LITLE: There is an erroneous impression among a great many people that the average pilot flame burner in the house consumes a great deal of gas. The pilot, as Mr. Jordan has very clearly shown in his paper, not only serves as a form of ignition for the gas burner itself, but also serves to give enough illumination in the room to be used as a night lamp, etc. Now that in itself is extremely valuable. The pilot on a gas lamp in a room can be said to perform the same function as the electric lamp that can be turned low by the pull of the chain. The pilot will enable one to see about the room and it must be considered as part of the illumination. Considering the convenience and very slight expense of such an arrangement for the various rooms in a house, I think it is possibly the cheapest form of night illumination.

Mr. Vaughn asked a question regarding street lamps. It is the practise in using pilots on street lamps, or for lamps used commercially in front of buildings, to protect the flame by some draft-proof arrangement. In Europe and America the usual

practise is to use a perforated cup. This scheme is working out very well. Remote control of street lamps and the clock and pressure wave lighting systems have been tried.

Mr. C. W. Jordan: In reply to Mr. Vaughn's inquiry regarding automatic igniters, I wish to refer him to an article published in the American Gas Institute *Proceedings,* Vol. VIII, 1913, Part II, by Mr. F. H. Gilpin, entitled "Automatic and Distant Lighters." This article thoroughly covers the application of many types of automatic igniters to American practise under the existing climatic conditions.

THE LIGHTING OF A PASSENGER STEAMER.*

BY H. T. SPAULDING.

Synopsis: This paper introduces the subject by a brief historical sketch of past and present practise in marine lighting. The lighting requirements of a passenger boat are discussed and compared with similar installations ashore. To illustrate how these requirements can be satisfied the author describes the lighting system designed by him, in co-operation with the architects, for the S. S. Noronic, a lake passenger boat, and gives the results of illumination tests in some of the more important portions of the vessel. In conclusion it is recommended that a departure be made from the ordinary boat lighting systems so common at present, and it is urged that a closer relationship between marine architects and illuminating engineers be established.

Boat lighting is similar with regard to the question of utilization efficiency and choice of system of illumination to installations on land having similar requirements, and it is therefore not the intention in this paper to cover these subjects. There are, however, certain factors governing marine lighting which are different from those usually encountered, and it is these factors, together with the requirements, and the manner in which they can be satisfied, that are to be discussed and illustrated by means of a description of the lighting of the S. S. Noronic, which was designed by the writer in co-operation with the architects of the interior finish and decoration.

There is a tendency among marine engineers to regard the cost of generating power as a small item, and this has resulted in the continued use of carbon lamps to a considerable extent for boat lighting. Insufficient attention has also been given to the installation of the lamps and their equipment to conform with the principles of good lighting, and reduction of glare. It is not uncommon to find a boat with elaborate equipment in all other respects fitted with bare lamps studded in the ceiling, or perhaps, equipped with so-called decorative glassware mounted upon fixtures at such a height that they are directly in the line of

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

vision. This is well illustrated in a paper[1] read before the New York section about three and a half years ago which was descriptive of the lighting systems on a number of boats of various classes in service at that time. Figs. 1 and 2, which are photographs of the social hall and dining room respectively on one of our lake boats, show installations typical of the methods commonly employed. In Fig. 1 the lighting units shown are all-frosted carbon lamps. The lighting of the dining room is more satisfactory as tungsten filament lamps are used and glare is somewhat reduced by means of diffusing glassware. The lighting is, however, hardly in keeping with the remainder of the appointments of the boat. No radical changes in the methods illustrated have been made in the last few years, except in the case of a few of the more recent, larger boats.

A passenger boat has requirements similar to a hotel, with its divisions corresponding on a smaller scale to the rooms used for similar purposes on land. The entrance hall, like a hotel lobby, should be brilliantly lighted. Social halls, as a rule, require less illumination; but as these rooms are often used for reading, it is necessary that the light be well diffused, and glare eliminated. Enclosing glassware, semi-indirect, or indirect fixtures will fulfill the requirements but usually the low ceiling height interferes with the use of the last two systems. For parlors, observation rooms, drawing rooms, and smoking rooms similar requirements, and also the same limitations, exist. Dining rooms should have a higher intensity, and here it is often possible to make use of semi-indirect lighting regardless of the low ceiling. As the tables are usually fixed, lighting units located directly above them will not interfere with the necessary head room.

The more pretentious suits are very similar to hotel guest rooms in every respect, and their lighting requirements are identical, but the ordinary staterooms require a different treatment. They are usually of such a size that a single low wattage lamp is ample for all needs, and the small space between decks, together with the berth arrangement, practically limits the location to the side walls. This is one of the few places on a boat where the use of bare, all-frosted lamps cannot be criticized, although

[1] Porter L. C., The Lighting of Passenger Vessels; TRANS. I. E. S. Vol. VII, p. 116, 1912.

equally satisfactory illumination and improved appearance will obtain if clear lamps equipped with diffusing glassware are used. Berth lights similar to those used in train lighting are a convenience greatly appreciated, and should be installed whenever the expense is not considered prohibitive. Writing rooms, barber shops, lavatories, passages etc., can generally be treated in the usual manner. An appendix is attached giving the intensities of illumination to be recommended and the equipment desirable for lighting the various portions of a passenger boat.

Mention has been made above to the limitations imposed due to the low ceilings almost universally found on boats. The space between decks is not often over 8 ft. (2.44 m.), usually less, so that by the time the thickness of the deck, the depth of the deck beams and the ceiling finish are subtracted, there is little space available for the lighting unit. Steel deck beams are common, and increase the difficulties of electrical construction. Usually the floor of the deck above forms the ceiling of the one below, and hence there is no space in which the wiring can be concealed or the lighting units recessed. Shallow bowls, very close ceiling fixtures, or a suspended ceiling with recessed lighting units, are some of the methods in which the difficulty can be overcome. Wall brackets, or lamps set into the partitions behind diffusing plaques can also be employed in certain cases. Generally, however, the necessity for utilizing all possible space has resulted in the partitions being constructed of but a single thickness of wood, so that there is little chance of recessing the units; in fact there is little space in which to run conduit for wall brackets.

The Northern Navigation Company's S. S. Noronic was designed to be one of the best and most completely equipped boats upon the lakes, and the finish, furnishings and lighting equipment were given more than usual consideration. Five decks are devoted wholly or in part to the use of the public. At the entrance on the main deck, a small hall, panelled in oak, leads to the stairway to the spar deck. Here are the office and lobby. On this deck are also located 150 staterooms, each equipped with hot and cold running water. The promenade deck above contains the smoking room, ladies' drawing room or lounge, 10 parlor rooms, social hall, and additional state rooms. The finish throughout is

Fig. 1.—Social hall of lake passenger boat.

Fig. 2.—Dining room of lake passenger boat.

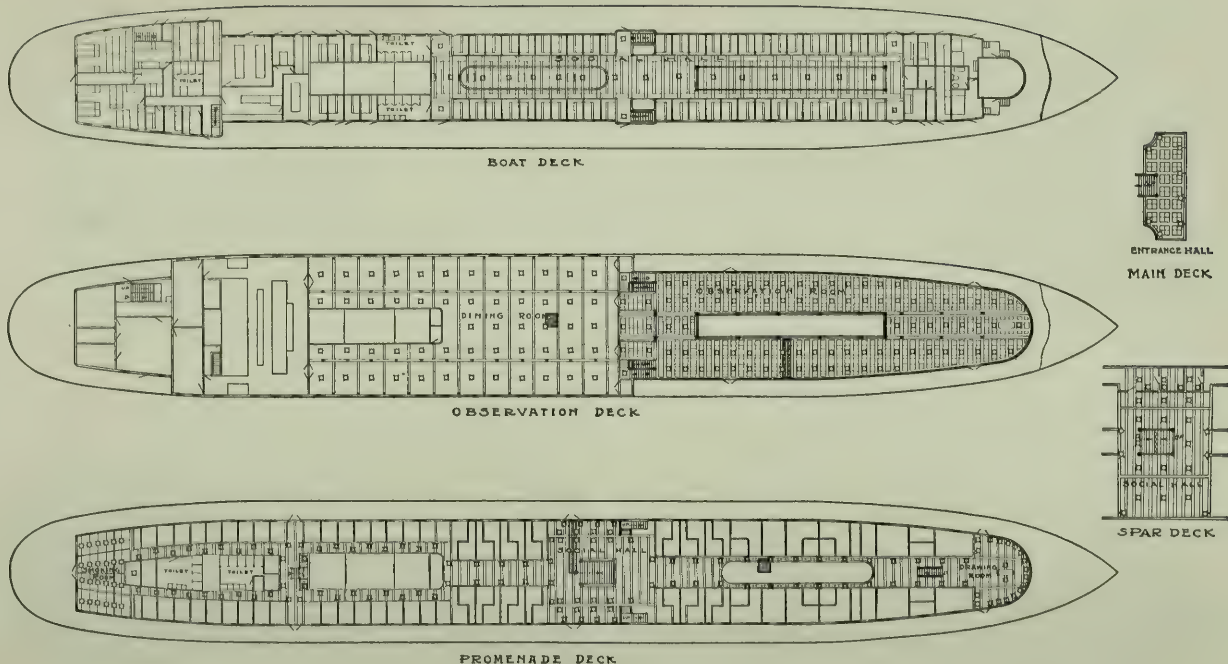


Fig. 3.—Deck plans of S. S. Noronic.

in panelled mahogany. The public portion of the fourth or observation deck consists of only two rooms, the observation room and the dining room, with an orchestra platform between. The dining room is finished in mahogany and light green, while the observation room, enclosed on three sides by large windows, has rugs, upholstery, hangings, and woodwork in a greenish gray tone. The boat deck contains, in addition to the pilot house and officers' quarters, a social hall panelled in light oak which is utilized as a writing room. Fig. 3 which is a plan view of the various decks, shows the arrangement of these rooms, and the location of all lighting outlets in the public areas of the boat.

In designing the lighting system, the unusual good fortune was experienced of being called upon before the plans of the interior were complete, and within limits, other considerations were secondary to the satisfaction of the principles of good lighting and the architectural requirements. The following paragraphs describe the lighting units installed and some of the features influencing their choice.

The lighting of the dining room is somewhat of a departure from the usual methods, in that semi-indirect lighting was employed with the outlets so arranged that a bowl was suspended directly over each table. A ceiling at the level of the under side of the deck beams was provided with a small circular panel above the lighting unit, recessed, and finished with a smooth surface, so that the brightly lighted area directly above the lamp was circumscribed. Even with the low ceiling height, about 7 ft. (2.13 m.), and the short fixture length, this arrangement resulted in the ceiling appearing fairly uniformly lighted, and provided a contrast to the relief decorations upon the remainder of the ceiling. To insure that the entire effect would be pleasing, a full sized model of a portion of the ceiling was constructed and a large number of bowl and lamp combinations were investigated before the one finally approved was adopted. A heavy density bowl[2] 16 in. (40.64 cm.), in diameter, etched with a special design harmonizing with the decorations as shown in Fig. 4a, was used with a 100-watt round bulb lamp. Fig. 5 is a view of the room with the lamps on. Illumination readings in a horizontal plane at the table level were taken in the representative area

[2] No. 1265 Calla 72 bowl.

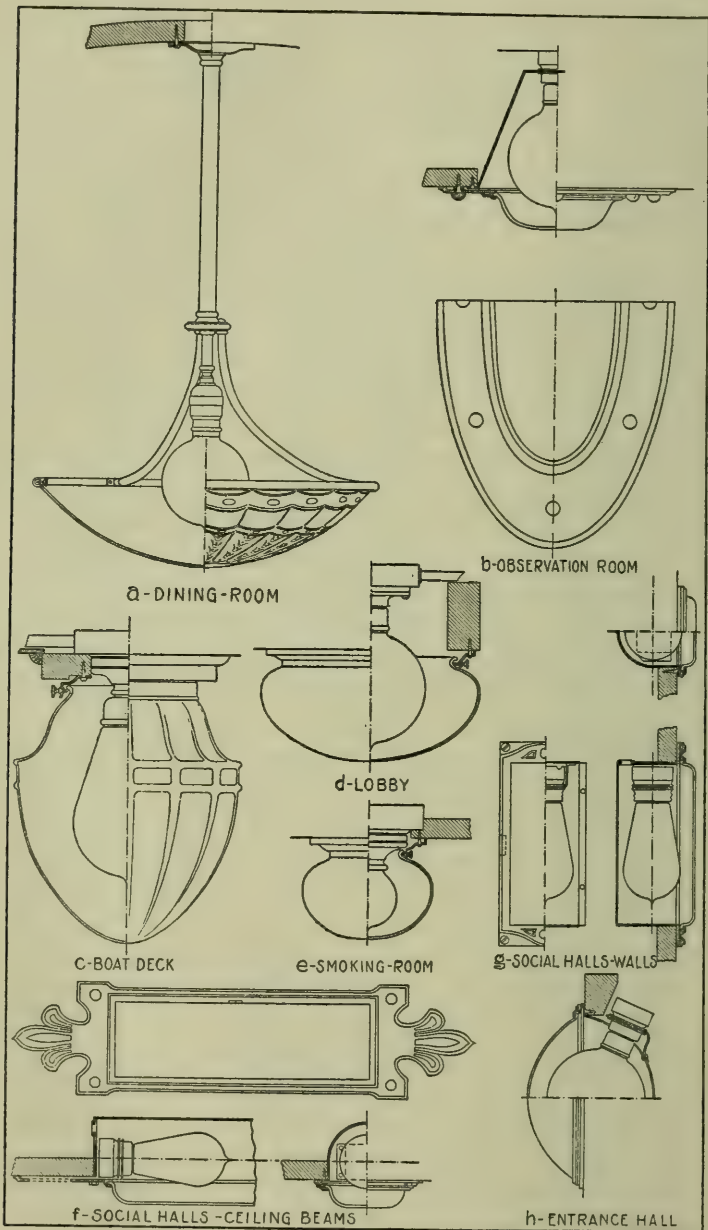


Fig. 4.—Fixture designs for S. S. Noronic.

shown by the shading in Fig. 3. At the time of the test the boat was not in commission, and the voltage was about 3 volts below normal. The lamps had been burned over half their rated life, and lamps and glassware were not cleaned previous to the test, so that the intensity of 3.7 foot-candles obtained after correcting for voltage is indicative of average conditions.

The low clearance in the observation room prevented the use of any type of fixture which would project far down from the ceiling, and the area of the room was such that lighting from the side would not have produced satisfactory effects. It was possible, however, to employ a suspended ceiling, with a few inches between the ceiling and the deck above in which the lamps could be recessed, and this course was decided upon. An eliptical dish[3] was used as a relief from the uniformity of the square ceiling panels. In the opinion of the architect it was also desirable because of the note of individuality conveyed. A single 100-watt round bulb lamp, backed by a white enamelled reflector was made use of for these fixtures as shown in Fig. 4b. It would have been possible to have a more shallow dish with two lamps burning horizontally except for the fact that the architect, for esthetic reasons, desired that the dish should not be lighted with absolute uniformity, but should show a brighter area near the center. A test in the area shown, with conditions as outlined above, gave 1.8 foot-candles in a horizontal plane 2.5 ft. (0.762 m.) above the floor. Fig. 6 is a daylight view of this room with the lights on.

For lighting the writing room or social hall on the boat deck, and for the portion of the promenade deck below the light well extending down through two decks, a single row of 250 watt lamps, with totally-enclosing diffusing globes[4] of the design shown in Fig. 4c, were located on the ceiling of the boat deck.

The smoking room and lobby were handled in about the same manner. The "squat" ceiling bowls shown in detail in Fig. 4d and 4e were used. Shallow bowls were necessary in these locations to allow of sufficient headroom, and a heavy density glass was chosen to conceal the lamp filament. Twenty-five–watt

[3] Alba glass No. 3772.
[4] Druid glass No. 01218 12 in.

lamps were used in the 6-inch (15.25 cm.) bowls[5] in the smoking room; and the 10-inch (25.4 cm.) bowls[6] in the lobby were equipped with 100-watt lamps. Here, as in a number of other locations, it was necessary to use the round bulb lamp because of its shorter over-all length.

The ceilings of the lounge, and the social halls on the spar and promenade decks were beamed, with insufficient room below to permit the use of even a shallow dish, and with so small a space between the ceiling in the panelled portions and the floor above, as to prevent the location of units in these areas. It was found that the narrow hallways and the portions of the larger rooms adjacent to the walls could be cared for by means of side lighting. For this purpose the oblong plaques[7] shown in Fig. 4f were developed. The illumination of the central portions of the larger areas was brought up by recessing larger plaques[8] of a similar shape in the sides of the ceiling beams. A single 60-watt lamp was used in the wall outlets, and those on the beams contained either two 25-watt or two 60-watt lamps, depending upon the location. Details of the larger units are shown in Fig. 2g. Illumination measurements taken at representative points showed an illumination upon a horizontal plane 2.5 ft. (0.762 m.) above the floor averaging about 0.7 foot-candles. The vertical illumination was higher, and as the function of the lighting in most of these portions is only to enable the passengers to see their way around, the results were satisfactory. In those rooms which were likely to be used for reading, a higher wattage was installed, so that the illumination was ample. Fig. 7 shows the lighting of the social hall on the promenade deck, and also the units installed on the ceiling of the boat deck above the well.

The entrance hall on the main deck was also lighted by means of wall plaques,[9] but of a somewhat different design. The means which it was necessary to employ to obtain sufficient wattage in the allowable space is shown in Fig. 4h.

The lighting of the staterooms was accomplished, as is the usual custom, by means of all frosted lamps on wall brackets at

[5] Sudan glass No. 431 6 in.
[6] Calla glass No. 328 10 in.
[7] Alba glass No. 3370.
[8] Alba glass No. 3771.
[9] Sudan glass 4½ in. × 2½ in.

Fig. 5.—Dining room of S. S. Noronic.

Fig. 6.—Observation room of S. S. Noronic.

Fig. 7.—Social hall of S. S. Noronic.

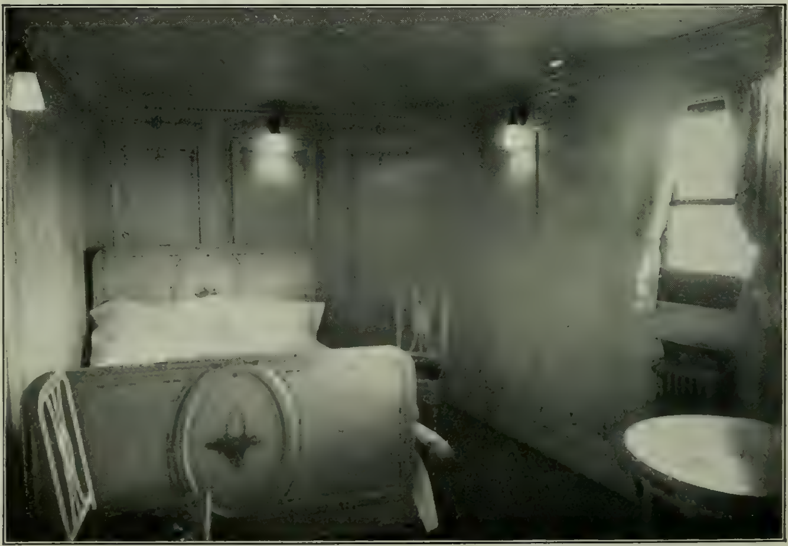


Fig. 8.—Parlor room of S. S. Noronic.

the side of the mirror. Each berth was also equipped with a small lamp. The parlor rooms contained a number of wall brackets fitted with dense opal shades as shown in Fig. 8.

While the illumination in no part of the boat might be considered as brilliant, yet it was found to be entirely satisfactory. This is due in part to the isolation from other contrasting brilliant illumination, but primarily to the fact that no bright light sources are within the field of vision.

In conclusion, I wish to extend my thanks to the Northern Navigation Co., the architects, the Holophane Works, and to Mr. Ward Harrison, for co-operating in securing and preparing the material for this paper.

APPENDIX

Recommendations for Passenger Boat Lighting.

Location	Intensity foot-candles	Equipment and location
Baggage room	1.0–1.5	Direct lighting—Glass reflectors at ceiling.
Ball room	2.0–3.0	Enclosing glassware at ceiling, or wall fixtures.
Barber shop	4.0–5.0	Semi-indirect units over or near chairs.
Bath-room	1.5–2.0	Diffusing glassware, or all frosted lamps on wall brackets at side of mirrors.
Cafe	1.5–2.5	Enclosing glassware, or direct reflectors of warm tone on ceiling or wall fixtures.
Dining-room	3.0–4.0	Enclosing glasswase, or semi-indirect units.
Drawing-room	1.5–2.5	Enclosing glassware or wall fixtures.
Freight deck	0.5–1.0	Steel distributing reflectors.
Grand saloon	1.5–2.5	Enclosing glassware, semi-indirect, or wall fixtures
Halls	1.0–1.5	Wall fixtures.
Kitchen	2.0–3.0	Direct lighting—Glass reflectors at ceiling.
Lobby	1.5–2.5	Enclosing glassware, or wall fixtures.
Lounge	1.5–2.5	Enclosing glassware, or wall fixtures.
Observation room	1.5–2.5	Enclosing glassware, or wall fixtures.
Office	3.0–4.0	Direct lighting glass reflectors at ceiling, or on brackets over desks.
Parlor	1.5–2.5	Enclosing glassware, or wall fixtures.
Parlor rooms	1.0–1.5	Wall brackets with diffusing glassware.
Passages	0.5–1.0	Wall fixtures.
Social hall	1.0–2.0	Wall fixtures, or enclosing glassware at ceiling.
State rooms-general	—	Diffusing glassware, or all frosted lamp on bracket at side of mirror.
State rooms-berths	—	Low candlepower all frosted lamp in each berth.
Toilets	1.0–1.5	Direct lighting glass reflectors at ceiling, or wall bracket with diffused glassware.
Writing rooms	2.5–4.0	Enclosing glassware at ceiling, or special direct lighting on tables.

DISCUSSION.

MR. L. C. PORTER: It seems to me there is considerable difference in the illumination problems of ships and those on land, because on most ships the finish is almost entirely white and this makes considerable difference in figuring the amount of light necessary. In regard to the tendency among marine engineers to regard the cost as a small item—the cost of generating power is not the only figure that enters into the calculation. The cost of installation makes considerable difference. In ferryboat lighting it is customary to use a large number of small lamps located on each side of the passenger compartment. In a recent boat the wattage was reduced to one half and the installation cost to one third the figures considered common practise. This was done by using a small number of large lighting units located down the center of the cabin instead of a large number of small units located in wall brackets.

The ceiling over the social hall (Fig. 7) is rather high. This is the typical condition in river and lake steamers. For such places having high ceiling room the open mouth reflectors can be used to advantage and a little more efficiency gained than is obtained through the totally enclosing globe.

The foot-candle illumination given for the observation room, seems to be a little high. On the Washington Irving, the largest river steamer in the world, a low illumination in the observation room was desired because passengers usually like to see what is outside, particularly along towards evening and at night. With a high illumination inside the observation room one cannot see the scenery outside as well as when there is a low illumination in the observation room. I believe that half a foot-candle would be much better than a value near two.

MR. W. R. MOULTON: The lighting problems in boat construction are rather unusual, therefore very interesting. The decoration of boat interiors is usually favorable to good lighting. On the other hand special conditions confront one, such as the low head room and the rafter ceiling construction.

I have recently had some interesting experience in lighting two private yachts, where each room seemed to present a problem of its own. In one the cabin was very low, and there was a

birth seat along either side. Inverted brackets equipped with heavy density opal reflectors were placed about 12 in. from the ceiling. The upper side wall, the bulkhead and deck were finished in light ivory which assisted in producing a very pleasing lighting result. Light was reflected from the side wall and also from the ceiling, and some penetrated the shades.

The pilot house ceiling was but 6 ft. 2 in. high. The owner desired it lighted from a center ceiling outlet. It was necessary to use a shallow bowl-shaped dome of medium density opal, directly at the ceiling. This was about 8 in. in diameter and about 3 in. deep. On account of the size of this unit it was impossible to use standard lamps; so two 15-watt candelabra base tubular lamps were used. The use of special lamps for such circumstances is surely justified.

On the same yacht electric running lights were installed. It is a serious offense, subject to a heavy fine and also very dangerous, for a boat to operate without running lights burning. To give proper warning as to the operation of the running lights, tell-tale lamps were installed in the pilot house, connected in series with the main lamps. If these tell-tale lamps were burning, they indicated that the running lights also were burning. The tell-tale light not burning, immediately warned the pilot of the outage of his running light; he could then either replace the electric bulb at once, or place a temporary oil lamp in its stead.

Mr. H. T. Spaulding (In reply): There is only one point which I wish to mention and that is in reference to the observation room. This area was also to be used at various times as a ball room and consequently sufficient lighting for this use had to be provided.

SEMI-DIRECT OFFICE LIGHTING IN THE EDISON BUILDING OF CHICAGO.*

BY WM. A. DURGIN AND J. B. JACKSON.

Synopsis: The equipment of a typical office test room and comparative tests on five lighting systems to show relative eye fatigue, glare, shadows, uniformity of intensity on desk plane, utilization efficiency and effective flux color, are described. The test results, leading to the development of a particular semi-direct unit for lighting the offices of the Commonwealth Edison Company, are discussed and the details of the adopted fixture structure and glass bowl characteristics presented. Data are given on the illuminating effectiveness, arrangement, appearance, and dust factor of the completed installation, especial emphasis being placed upon the importance of the use of higher intensities and filtered flux.

The great stride in the economical generation of light flux achieved in the one-watt and higher efficiency incandescent lamps, has enlarged the resources of the lighting engineer many fold. In the age of the three-watt-per-candle lamp it was necessary to consider all radiation which was capable of exciting the optic nerve as valuable illuminating material if lighting was to be accomplished at reasonable cost, and the lowest intensity under which seeing became moderately comfortable was perforce regarded as satisfactory. Flux generation at three to five times this efficiency, however, permits economical use of much higher intensities, and the filtering of the light to secure only those color components which are best adapted to producing the desired effect.

Such higher intensities and controlled light quality may or may not prove to be the ultimate solution of the good-lighting problem. The possibilities at least are most attractive, but only extended experience with installations involving considerable departures from the current usage in intensity and flux color can evaluate these characteristics.

The lighting of offices aggregating 82,000 sq. ft. (7,600 sq. m.) for the use of one of the largest central station companies has

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

given opportunity for applying these ideas, and this paper presents some account of the preliminary tests of various possible systems and of the development and final installation of a special unit embodying the features of color modification and high intensity while meeting the more generally recognized requirements of acceptable illumination.

For the preliminary tests a typical office in the new building of the Commonwealth Edison Company was equipped with metal moulding and outlets to permit a symmetrical two, four or six unit installation. The room was approximately 24 ft. 6 in. (7.5 m.) long, 19 ft. (5.8 m.) wide, and 10 ft. 6 in. (3.2 m.) high. Three sides were clear wall space and although the fourth or corridor side contained the door and a line of windows, all glass was covered with heavy coatings of calcimine to match the walls. With the exception then of the baseboard, chair rail, picture moulding, lower panels of door, and frames of corridor windows, all of which were finished in dark mahogany, the entire wall surface of the room was calcimine.

The tints chosen were light cream for the ceiling (reflection coefficient for vacuum tungsten lamp flux 0.8), dark cream for the walls above chair rail (reflection coefficient 0.7), and light brown below. The floor was bare maple. It was originally intended to test several color schemes, but this first selection proved so satisfactory to the committee charged with the final approval of the installation that it was adopted and no other tints considered. An outline of the room showing position of the outlets, as well as the desk employed in eye fatigue tests, is given in Fig. 1.

Five distinct methods of office illumination were investigated: direct lighting with prismatic reflectors in velvet finish; direct lighting, with opal reflectors giving very light amber tone; semi-direct lighting with art glass reflectors of amber tone; semi-direct lighting with dense opal reflectors of slightly greenish tone; and indirect lighting, with silvered glass reflectors. Each of these systems was tested for eye fatigue, glare, shadows, color of the light, uniformity of intensity on 30-inch desk plane, and utilization efficiency for this plane. The detail of test equipment and procedure will be found in Appendix I, the principal results being summarized in Table I, and the following paragraphs:

TABLE I.—SUMMARY OF PRELIMINARY RESULTS.

Equipment			Intensity (Mean foot-candles)	Uniformity (Ratios of intensities)			Glare (Brightness in millilamberts)		Utilization efficiency (Per cent.)
No. of units	Glassware	Lamps per unit		Max./Min.	Max./Mean	Min./Mean	Walls	Ceiling	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Direct:								
6 in o_6	Velvet prismatic	1/100-watt	4.6	1.3	1.1	0.8	2.8	1.8	43
6 in o_6	Amber opal	1/100-watt	4.8	1.4	1.1	0.8	2.5	1.7	45
6 in o_6	Velvet prismatic	1/60-watt	3.1	1.3	1.1	0.8	0.9	0.3	48
6 in o_6	Amber opal	1/60-watt	3.0	1.5	1.1	0.8	0.8	0.7	47
	Semi-direct:								
4 in o_4	Art glass	1/125-watt*	4.0	1.8	1.1	0.6	0.9	0.5	44
4 in o_4	16″ dense opal	4/40-watt	4.3	1.7	1.2	0.7			42
2 in o_2	Art glass	1/250-watt	4.5	2.6	1.5	0.6			44
2 in o_2	20″ dense opal	1/250-watt	3.9	2.5	1.5	0.6	0.7	1.5	45
	Indirect:								
4 in o_4	Silvered glass cone	1/150-watt	3.4	1.7	1.2	0.7	1.8	2.1	36

* Two units equipped with 1/100-watt lamp each and two with 1/150-watt lamp each.

TESTS.

Eye Fatigue.—The results of the Ferree tests made a part of this investigation by Mr. J. R. Cravath have been presented previously to the society.[1] The judgment of the subject in these tests and of the present authors, a judgment substantiated as to the order of excellence, if not entirely as to the degree of superiority, by the Ferree tests was as follows:

Both direct lighting systems showed marked inferiority to the semi-direct and indirect systems when rated by eye fatigue. The

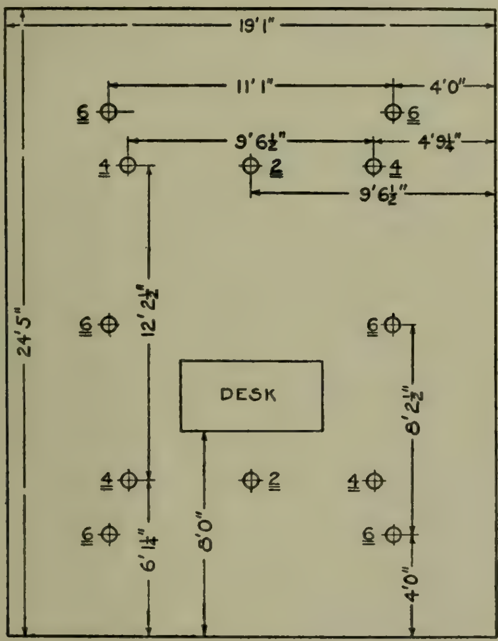


Fig. 1.—Plan of test room. Underlined figures indicate outlets used with corresponding number of units in symmetrical arrangement.

preference of the testers was for the art glass semi-direct system due probably to the amber tone of the light and the attractive appearance of the units, but both semi-direct installations were very satisfactory.

Glare.—All observers were impressed with strain resulting from the excessively bright walls under the direct system. As

[1] Cravath, J. R., Some Experiments with the Ferree Test for Eye Fatigue; TRANS. I. E. S., vol. IX, p. 1033; 1914.

computed from column 8, Table I, which gives the measured value of the brightest area on the walls below the picture moulding, the 100-watt direct units produced a wall brightness of the order of one half that of a mat white paper on the desk plane, deduced from the mean intensity shown in column 4, Table I. The semi-direct system when reduced to the same horizontal illumination gave only one third as high wall brightness, and with the walls thus about one sixth as bright as the paper upon which the observer was working no strain was noticed. The high wall brightness shown under the indirect system is somewhat misleading as it applied only to a narrow strip near the picture moulding which would rarely come within the field of view. The testers' judgment indicated that both semi-direct and indirect systems were satisfactory as regards wall glare, and that all three were reasonably good in reducing desk glare, although the art glass, semi-direct reflectors were of such light density as to be inferior to the heavy density semi-direct and the indirect systems. In the desk work with the direct system the surface reflection glare from the desk top and glazed paper was very trying.

Ceiling brightness perhaps is rather outside the glare question since in medium-sized offices ordinary lines of sight bring no part of the ceiling into the field of view. It is interesting to note, however, that, as shown in column 9, Table I, a small part of the ceiling immediately above the direct units was quite as bright as any part with the semi-direct units and two thirds as bright as the ceiling illuminated with the indirect silvered reflectors when the figures are reduced to the same horizontal illumination. This unusual result was produced by the high mounting of the direct units, which brought the glowing reflectors within a few inches of the ceiling.

Shadows.—The bookkeeper working under the various systems was much annoyed by the multiple shadow from the two six-unit direct lighting installations. While some shadow resulted with the light density semi-direct system it produced no comment and appeared acceptable to all observers for office work, as did the almost total lack of shadow from the other two systems. Shadowgrams, made as outlined in Appendix I, served to record the conditions of light direction for the inspection of the

lighting committee and to display the difference between the clear-cut and comparatively dense shadows from the direct system, and the hazy outline and lesser density of those from the art-glass semi-direct installation. The practical equality of a moderately dense bowl semi-direct system and the indirect system in lack of shadow production was especially well shown and it was agreed that each of these installations diffused the light too much for the best esthetic effect.

Color of Light.—The warmer tone of light from the art-glass semi-direct units was very agreeable, while the similar color from the opal-glass direct system was responsible probably for a considerable portion of its apparent visual superiority over the prismatic equipment. Both semi-direct and indirect systems took their color tone to a marked extent from the ceiling and the harshness of the tungsten flux was somewhat reduced in this way. The wide variations in density of shadowgraph films obtained from the several systems with identical exposures served to emphasize the effect of color modification in those systems depending largely upon ceiling and wall reflections.

Accuracy of Data.—The usual ratios between the maximum, mean, and minimum illumination values observed on the 30-inch plane are shown in columns 5, 6, and 7 of Table I. It will be noted that these are given only to two places of significant figures, and the authors wish to call especial attention to the desirability of thus reducing the pretension to accuracy found in many illuminating data. The maximum or minimum ratio is based on a few readings at a single station and any extended experience with the portable photometers at present available will convince the tester that there is little probability of such value having an error less than 5 per cent. while even in careful work errors of 10 per cent. at a single station frequently occur. Furthermore in the present state of lighting a 10 per cent. variation in the uniformity ratios or indeed in such characteristics as mean intensity or specific brightness have a negligible effect on the excellence of the installation and cannot be appreciated by the most experienced engineer. Two places of figures thus generally carry the result beyond the point of uncertainty, and give more than adequate numerical precision.

Uniformity of Intensity.—The uniformity produced on the 30-inch plane by the five systems under consideration appeared largely independent of the system used, being chiefly determined by the spacing and suspension height. In the direct system using six units mounted at the ceiling the maximum intensity was but 10 per cent. above and the minimum 20 per cent. below the mean. With the indirect and dense semi-direct systems the maximum was 20 per cent. above the mean and the minimum 30 per cent. below it. This last variation was not considered excessive, a high mean value assuring sufficient illumination at all points.

Utilization Efficiency.—The utilization efficiencies obtained are given in column 10, Table I. Those for the direct lighting systems are open to some question on account of the necessity, noted in Appendix I, of assuming the flux generated by the lamps before they were bowl frosted; but as the means of six units are believed to be fairly reliable. The figures for the semi-direct and indirect systems were computed from flux values based on actual photometric measurements and should have high accuracy.

The unusually high mounting of the direct units adopted in an attempt to decrease glare and shadow, reduced the efficiency of the direct systems, while the exceptionally low absorption of the ceiling and walls greatly increased the efficiency of the semi-direct and indirect systems as compared with similar tests made in other offices.

With the possible exception of the indirect system, there was not sufficient difference in the efficiencies found to influence the final choice. Indeed utilization efficiency is believed to be of far less importance with the higher-efficiency lamps and if the losses of generated flux are expended to secure better diffusion or preferred color, the increased effectiveness may largely overbalance the cost of absorption.

General Conclusion from Preliminary Tests.—The superiority of the semi-direct and indirect systems over the direct in lessened eye fatigue and in harsh shadow elimination seemed to the lighting committee to greatly overbalance the decreased utilization efficiency, lessened uniformity and increased investment costs of these more diffusing systems. As between the semi-direct and indirect system, the advertising value of a visible light source in

the offices of a company supplying light, a more ready control of flux color and shadow density, and a somewhat higher utilization efficiency led to the recommendation of the semi-direct system, with the provision that semi-direct and indirect units of closely similar design should be developed and that each department head should decide which was to be installed in the offices under his direction. This parallel design was carried out and the indirect system chosen for the drafting room, where all agreed that the minimum glare on tracing cloth made it ideal, and for about 5 per cent. of the offices. This represents such a small part of the total floor area, however, that no further consideration is given the indirect system in the present paper.

SEMI-DIRECT LIGHTING REQUIREMENTS.

The necessary characteristics of a satisfactory semi-direct unit were considered to be: (a) Bowl brightness not more than three times that of the ceiling. (b) Reasonably high overall efficiency. Hence a high reflection coefficient for the bowl interior and little interference from fixture structure. (c) Color modification of tungsten flux to a warmer tone. (d) Easy cleaning of bowl and lamps.

Choice of Bowl.—The first requirement, moderate brightness of bowl, served to eliminate a large proportion of the glassware on the market. Twelve types of bowls submitted by eight manufacturers were equipped with three 100-watt lamps each and hung 30 in. (76 cm.) from the ceiling on 14 ft. (4.3 m.) centers in a long office some 11 ft. (3.4 m.) in height. An indirect fixture, similarly equipped and hung produced a maximum ceiling brightness, viewed from a point directly below, of 80 millilamberts. Assuming, as seemed highly probable, that no semi-direct equipment could produce higher ceiling brightness under these conditions, the desirable bowl brightness was limited to 240 millilamberts. The average brightness of the bottom of twelve bowls tested was 1,170 millilamberts viewed from below, and the average side brightness at the 80° angle was 340 millilamberts. One bowl of a widely used glass had a bottom brightness of 4,600 millilamberts and several a side brightness of over 500 millilamberts. Frequently such excessive values were caused by the shape of the bowl placing the glass too near the lamps when their

position was adjusted to bring the bulbs below the top plane of the fixture ring; but it is believed that in addition to too shallow bowl shapes at least 90 per cent. of the glassware now offered for semi-direct use has much too high transmission.

The bowl finally chosen[2] met all the requirements satisfactorily. The bottom was about 2.7 times as bright as the brightest spot in the ceiling and the side of practically ceiling brightness. The depth, 6½ in. (16.5 cm.) for a 20 in. (51 cm.) bowl and 5¼ in. (13.3 cm.) for the 16 in (41 cm.) size, conduced to this result; but the density of the triple-cased glass used was the principal factor. Measurements made in the office shown in Fig. 4 gave the values of Table II.

TABLE II.—BRIGHTNESS VALUES IN OFFICE EQUIPPED WITH EIGHT SEMI-DIRECT UNITS.

	Millilamberts	
	Mean	Maximum
Bottom of bowl	150	190
Side of bowl	60	90
Ceiling above bowl	55	60
Ceiling at center of four unit square	1.2	1.4
Ceiling at middle of side of four unit square	2.8	3.0
Side wall 6 ft. from floor	2.6	2.6
Side wall 4 ft. from floor	1.8	2.2

In so far as the glassware determined the efficiency of the unit the chosen bowl seemed exceptionally good, the interior surface being of pure white highly glazed and the regular and simple curve (see Fig 2), giving a moderately wide distribution. The cased glass permitted the toning of the transmitted flux to an amber of approximate visual color match to that produced by a metallized filament lamp at 96 per cent. rated voltage, while the bowl retained when not lighted an appearance of iridescent white. With the spectroscope this glass was found to absorb in transmission all the tungsten lamp spectrum above the blue-green, but in reflection from the interior surface the spectral composition was entirely unaffected. The high interior glaze was recognized also as of marked advantage for easy cleaning.

GLASS AND FIXTURE SPECIFICATIONS.

Purchase of Glassware on Specification.—To secure reasonable uniformity in separate shipments of some 700 bowls when color

[2] Calcite.

and brightness were of paramount importance, it appeared necessary to closely specify these qualities. Previous practise offered no published precedent and in consequence the specification shown in Appendix II was proposed and submitted to the manufacturer. This is presented not as a finished solution of the question, but as a focus for discussion of a seemingly neglected means for improvement of lighting practise. Even after conscientious inspection of each bowl by the manufacturer for compliance with the specification, the customer's inspector rejected 2.5 per cent. of the shipped bowls for size and 6.5 per cent. for uniformity of color. Without specification then, no approach to uniformity could be expected. Experience in this instance showed the glass manufacturer more than willing to cooperate in the effort to secure better product and although the rather narrow limits imposed lead to a very considerable number of rejections before shipment, both parties are convinced of the benefit of the plan. The expense to the customer of carefully inspecting each bowl for fit in a gauge ring, design, dimensions and quality of etching, for appearance when lighted with lamps grouped as in the completed unit, and for color tone as compared with a bowl selected as standard was less than 7 cents per bowl.

Fixture Design.—The principal desiderata in the fixture were an effect of substantial and simple design, small interference with generated light flux, and the inclusion of a double ring to permit easy cleaning. In the specification given to the various fixture houses the last feature was covered by the following statement:

"The scheme consists of a double ring, one ring to be stationary and to carry the socket equipment, the other securely hinged to the first, to be so arranged as to be dropped easily at one side for allowing ready accesss to the interior of the bowl for cleaning. The hinge must be at least 2 inches wide and of sufficient strength to carry bowl weight without wear. Means for locking the two rings together must be provided at a point diametrically opposite from the hinge, the locking scheme to permit quick separation of the bowls but to be of ample strength to support bowl weight. Means for securing the glass bowl in the lower ring easily and permanently also must be arranged. The design of the two rings should provide a rabbet or other overlap between them so that no leakage of light is possible."

The accepted realization of these ideas is well shown in Fig. 2, *a* and *b*. Two strap-iron rings are arranged to fit concentrically.

The outer ring carries a brass spinning to give the exterior finish and provide a lip for supporting the bowl, while the inner ring carries the lamp sockets and is in turn carried by the four supporting rods. Two of the three clips arranged to retain the bowl are shown in *b,* and the spring catch which holds the rings together may also be seen at the lowest point of the outer ring. This arrangement permits the bowl to be lowered in a few seconds, exposing both sides of the lamps for dusting and permitting the interior to be cleaned with a single sweep of a cloth. The entire dusting operation can be performed in less than two minutes.

Especial attention was given to lamp position, the socket location being specified by the resulting position of the lamp tips as shown in Fig. 6. This figure also shows the details of canopy employed. The particular point to be noted here is the iron bridge which carries the stress from the rod rings to the central hickey and by means of a nipple and lock nut supports the fixture when the canopy shell is removed, thus permitting the connection of wiring after the fixture is permanently in place. This construction was suggested by the manufacturer and is in more or less common use in fixtures, but is emphasized because of its strength and convenience.

Each fixture was inspected after hanging, the lamp position checked with the largest specified size of lamps and, where necessary, altered under the inspector's direction to give a uniform illumination of the entire bowl. As will be noted from the dimensions given in Fig. 6, the lamps were placed higher in the bowl than usual. This arrangement gives a breadth of distribution leading to a bright band on the upper part of the side wall if the unit is installed less than 6 feet from the wall, but is necessary, even with such deep bowls, if each bowl is to have that even gradation of brightness and freedom from spotting which is believed to be one of the most pleasing details of a good semi-direct unit.

Characteristics of Complete Unit.—The average 20 in. (51 cm.) bowl weighed 9 pounds and the efficiency of the unit was found to increase slightly for lighter and decrease for heavier bowls due to corresponding variations in transmitted flux. These varia-

(a) (b)

Fig. 2.—(*a*) Standard semi-direct unit: (*b*) 20-in. bowl opened for cleaning.

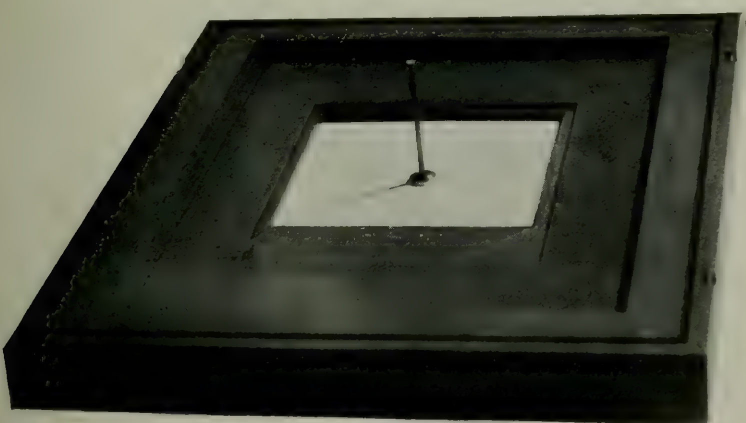


Fig. 3.—Shadowgraph apparatus.

Fig. 4.—Typical Commonwealth Edison Co. office lighted by eight semi-direct units on 14 feet centers.

Fig. 5.—Office of Fig. 4. with units converted to an indirect system.

tions, however, were not more than 1.5 per cent. from the mean unit efficiency of 80 per cent. A standard fixture equipped with a bowl weighing 8.7 pounds and three 100-watt tungsten lamps gave the distribution curves shown in Fig. 7, and summarized in Table III.

TABLE III.—DISTRIBUTION FROM SEMI-DIRECT UNIT.

	Lumens	Per cent.
Generated flux	2,875	100
Absorbed by fixture	15	0.5
Distributed by fixture without bowl in lower hemisphere	1,525	53
Distributed by complete unit	2,330	81
Portion of complete unit flux, in lower hemisphere	260	11
Portion of complete unit flux, between 105° and 180°	1,930	83

Curve B of Fig. 7 is of especial interest as it indicates the preponderance of flux in the lower hemisphere from the bare lamps caused by the downward tip of the bulb axes and the slight absorption from the fixture structure. Such absorption was reduced to a minimum by covering the interior of the fixture rings with aluminum paint and by the comparatively light supporting members employed. Photometer readings at 170° and 180° could not be obtained with the apparatus available, hence curve A was extrapolated for these points as indicated by broken line. This procedure should introduce a negligible error in the flux values as the zones affected are of small area.

In curve C the portion of curve A from 0° to 90° is redrawn at an enlargement of five times to show the intensive character of the distribution in the lower hemisphere.

COMPLETED OFFICE INSTALLATIONS.

The office floors of the Edison Building are arranged on three sides of an oblong court 60 by 120 ft. (18 by 37 m.) in extent and a central corridor divides a considerable part of each floor into an inner and outer space. This arrangement leads to three groups of offices approximating 20, 30 and 56 ft. (6, 9 and 17 m.) in width, many of the general clerical spaces being comparatively long while the private offices average 15 ft. (5 m.) square. The ceiling height varies from 10 ft. 1 in. (3.1 m.) to 17 ft. 3 in.

(5.3 m.), 44,000 sq. ft. (4,100 sq. m.) or nearly 54 per cent. of the total floor area having a height of 10 ft. 9 in. (3.3 m.).

The considerable range in width of offices necessitated a similar variation in the spacing of the semi-direct units. 14 ft. (4.3 m.) between centers was taken as the maximum and this distance may be considered standard, although spacings as low as 8 ft. (2.4 m.) were used in a few cases. In general the shorter spacings were employed in private offices and units with 16-in. (41 cm.) bowls installed carrying two or three 60 or 100-watt tungsten lamps.

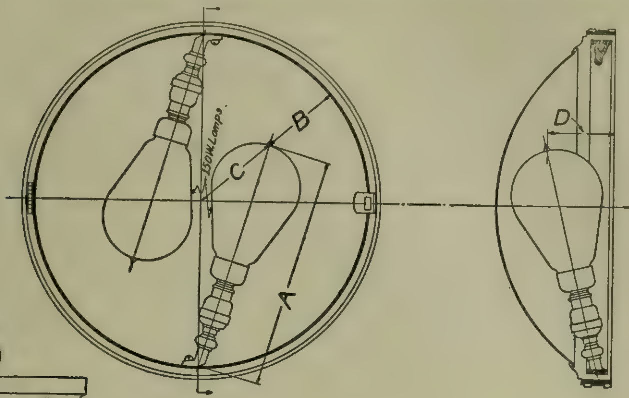
The complete system of offices required 250 of these 16-in. (41 cm.) bowl units, while 450 of the larger units equipped with 20-in. (51 cm.) bowls were used. Most of these carry three 100-watt tungsten lamps, but in a few instances 60-watt or 150-watt lamps are necessary to produce the standard mean intensity.

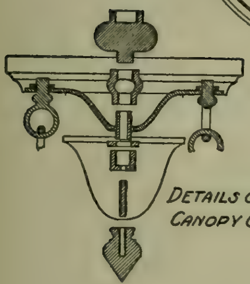
All offices were decorated with the cream and brown tints of calcimine described for the test room and after six months of use the reflection coefficients were found to be about 0.8 for the ceilings and somewhat above 0.7 for the walls.

Taking an office width of 28 ft. (8.5 m.), a ceiling height of 10 ft. 9 in. (3.3 m.), a spacing distance of 14 ft. (4.3 m.) and the larger or 20-in. (51 cm.) bowl unit with the upper edge of ring 30 in. (76 cm.) from the ceiling as representative of the installations, complete illumination tests under these conditions were made in two rooms, one 50 ft. (15 m.) and the other 100 ft. (30 m.) in length. The results check so closely that all data have been averaged together and are here presented as applying to any of the group of long offices having the stated width and height. The end-wall effect is to decrease the average illumination about 10 per cent. in a strip extending some 8 ft. (2.4 m.) from the wall and in offices approaching a square plan this affects the mean values to a small extent but in the longer offices is practically negligible. End walls, therefore, are neglected in the following discussion and the computations based on intensities obtained in the middle half of the rooms.

Illumination Tests.—To insure accuracy, checks were made simultaneously by two observers using separate Sharp-Millar photometers, one of standard and the other of small size. In those

(*a*)



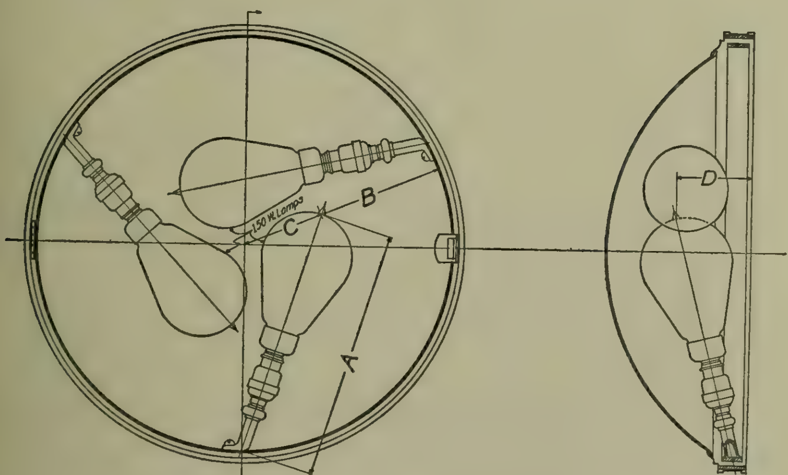


DETAILS OF CANOPY CONSTRUCTION

POSITION OF LAMPS IN 2 OUTLET FIXTURE

2 LAMPS 180° APART					
16" BOWL FIXTURE					
Indirect			Semi-direct		
	150W	100W		150W	100W
A	11¼"	10¼"	A	11⅛"	10"
B	4½"	4½"	B	2⅞	3⅜"
C	3½"	3½"	C	5⅛"	4⅝"
D	2½"	2½"	D	2¾	2½"

(*b*)



POSITION OF LAMPS IN 3 OUTLET FIXTURE

3 LAMPS 120° APART								
20" BOWL FIXTURE						16" BOWL FIXTURE		
Indirect			Semi-direct			Semi-direct		
	150W	100W		150W	100W		100W	60W
A	10½"	9½"	A	12½"	11¾"	A	10¾"	8½"
B	5"	5½"	B	6⅛"	6⅜"	B	4⅜"	5¾"
C	5"	4¾"	C	3⅞"	3⅜"	C	3⅝"	2¼"
D	2¾"	2½"	D	3½"	2⅝"	D	3⅛"	2½"

Fig. 6.—(*a*) and (*b*) Plan of lighting unit.

cases where results failed to agree the data were rejected or only those used from the instrument showing no change on recalibration. In this way it was possible to obtain mean values differing by less than 1 per cent.

The unavoidable variation in system pressure was met by taking readings from side-wall sockets directly on the distributing wiring, correcting for the measured drop to the fixture sockets and further correcting to a standard mean pressure of 113 volts. As there was some question of the relation between the intensity of the amber filtered flux and pressure, an extended series of readings was taken at five typical stations at five pressures ranging from 108 to 117 volts.

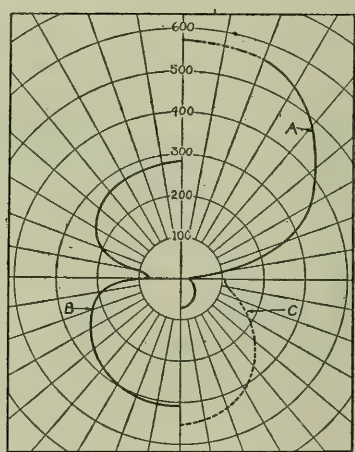


Fig. 7.—Distribution from 300-watt semi-direct unit. (*A*) Curve when equipped with 20-in. bowl. (*B*) Curve when equipped with lamps but no bowl. (3) Portion of (*A*) from 0° to 90°, enlarged five times.

These data were obtained for both the total semi-direct flux and for the indirect component, but when plotted showed an extreme divergence of only 1 per cent. from the accepted curves for tungsten lamps. The removal of the blue rays, therefore, has no appreciable effect upon the established flux-pressure relations.

In Figs. 4 and 5 two views are presented of the office which is 50 ft. (15 m.) in length. This room is equipped with eight units and Fig. 4 gives a close representation of the lively character of the illumination, of the moderate brightness of the

bowls, and of the absence of dense shadows. Fig. 5 presents the method used for separating the indirect component for measurement and suggests faintly the resulting flat appearance of the lighting. The oil cloth covers drawn over the bowls to shut off the direct component were grayish white on the outside and dull black on the inside thus producing minimum interference with the normal conditions of reflection from the bowl surfaces.

Summarized results from all illumination tests on clean bowls and new lamps are given in Table IV. The mean semi-direct intensity of 6.0 foot-candles on the 30-in. (76 cm.) plane corresponds to a utilization efficiency of 42.5 per cent. with 115-volt, 1-w. p. c. lamps operated at 113 volts, a flux of 2,770 lumens applying to an area 14 ft. (4.3 m.) square. The corresponding mean indirect intensity of 4.9 foot-candles, or a utilization efficiency of 35 per cent. is not far below that obtainable with the best indirect units and indicates the excellence of the interior finish and shape of the bowls.

TABLE IV.—ILLUMINATION VALUES FROM COMPLETED SEMI-DIRECT INSTALLATION.

	Intensities in foot-candles on 30 in. plane			Uniformity ratio		
	Max.	Mean	Min.	Max./Min.	Max./Mean	Min./Mean
Semi-direct	8.0	6.0	4.2	1.9	1.3	0.7
Indirect	5.6	4.9	3.7	1.5	1.1	0.8
Direct	2.8	1.1	0.7	4.0	2.5	0.6

The mean semi-direct illumination thus contains a direct component of 18 per cent., which although it is somewhat higher than the 12 to 15 per cent. advocated on theoretical grounds,[2] appears eminently satisfactory in affording a restful contrast and minimum eye fatigue. It should be noted that this 18 per cent. of illumination is given by 11 per cent. of the generated flux.

In Fig. 8 the relation of the three components are shown, the lower group of curves giving the relative intensities across the room on a line 30 in. (76 cm.) above the floor directly under the units, and the upper group, similar intensities midway between

[2] Symposium on Indirect, Semi-Indirect and Direct Lighting: TRANS. I. E. S., vol. VII, p. 234; 1912.

two such lines of units. The semi-direct intensity immediately beneath the bowl is taken as unity and all other intensities plotted in percentage of this value. Perhaps the uniformity of the indirect component and effect of the direct component in relieving the flatness are the most notable points indicated. The drop in intensity toward the side walls is also well shown. This produces a considerable decrease in the mean intensity and since many of the desks are placed toward the center line of these long offices, it may be fairly stated that an intensity of 7 foot-candles under clean units is being used by a majority of the clerks in

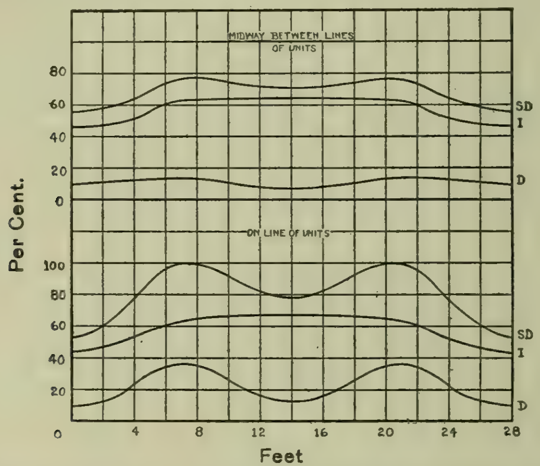


Fig. 8.—Illumination Curves to show relation of indirect and direct components to total flux on a 30 in. plane.

these rooms. Allowing 20 per cent. decrease before cleaning, the average value of the intensity for these desks is approximately 6 foot-candles. Wall brightness within the ordinary field of view as noted in Table II reaches values more than one-third those produced on matt paper under a 6 foot-candle illumination and would seem to be too high for best eye efficiency. As yet, however, no complaints of this condition have been received, due perhaps to the fact that a large part of the wall is covered by dark mahogany cases and that these high brightness values only apply to small areas where structural limitations have brought units close to an end wall. The greater part of the wall has a brightness about one fourth that of mat paper on the desks.

Dust Factor.—Extra care was used in securing the data for the dust deterioration curve, Fig. 9, and the plotted points from three locations representing the most dusty offices in the building show no departure from a straight-line law during the observation period of three weeks. As the absorption had increased to 25 per cent. at that time the further performance was considered of little interest. A bi-monthly cleaning schedule will insure an illumination at all times above 80 per cent. of the clean-bowl condition. Such a schedule is being made effective and although

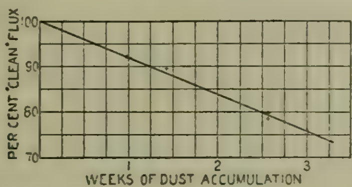


Fig. 9.—Dust absorption factor of standard C. E. Co., semi-direct office installations.

experience is not yet sufficient to permit accurate maintenance cost figures, the fixture design bids fair to reduce cleaning expense to a very nominal amount.

CONCLUSION.

In the use of a mean intensity above 6 foot-candles and of a distinctly amber tone of effective flux the office lighting in the Edison Building of Chicago represents an experiment. There is no question as to the immediate popularity of the results. Clerks and department heads agree in commendation. But the element of time is lacking as yet and only extended experience can show whether high intensities and filtered flux will prove a permanent advance.

The low value of bowl brightness and the fixture design employed are more confidently presented as realizations of generally accepted but rarely applied principles and the dust deterioration curve will give definiteness, it is hoped, to the much discussed question of semi-direct lighting maintenance.

The accumulation of data for this paper has been possible only through the cordial cooperation of Messrs. G. W. Baker and R. E. Powell of the Commonwealth Edison testing department and to them the authors tender their hearty thanks.

APPENDIX I.—EQUIPMENT AND PROCEDURE FOR PRELIMINARY TESTS.

Room.—Arranged as described in paper.

Wiring.—A system of metal moulding and outlets was installed on the ceiling whereby a symmetrical 2, 4, 6, or 8 unit system could be used. To insure accurate indication of the voltage applied to the lamps two pressure taps were arranged directly on the ceiling wiring. Provision was also made for measuring the current and installing a controlling rheostat at the switch cabinet.

Steadiness of Supply.—Recording voltmeter charts and frequent readings with indicating voltmeter showed the day pressure to be within + or — one volt of the mean value 112 volts. The average during each test was computed from twenty readings and the flux corrected to this value using National Electric Lamp Association curve[4] for variation of candlepower with pressure.

Lamps.—The lamp equipment comprised:

2 250-watt, 114-volt clear bulb lamps assumed to give standard average flux (2 x 2,450 lumens) at 114 volts.

4 150-watt, 116-volt clear bulb lamps photometered at 116 and 113.5 volts for m. h. cp. Flux computed using reduction factor of 0.785.

6 100-watt, 114-volt clear bulb lamps rated at 114 volts for m. h. cp. and total flux by General Electric Co.

6 100-watt, 114-volt bowl frosted lamps assumed to generate standard average flux (908 lumens) at 114 volts before frosting.

6 60-watt, 114-volt bowl frosted lamps assumed to generate standard average flux (526 lumens) at 114 volts before frosting.

6 60-watt, 114-volt bowl frosted lamps photometered at 112 volts for m. h. cp. and flux computed using reduction factor of 0.785.

Glassware Equipment and Mounting Heights.—

1. Prismatic reflectors X-I 100, velvet finish used with form H holder mounted at 9 ft. 9 in. (3 m.) from the floor to lower edge.

[4] Engineering Department, National Electric Light Association Bulletin 13C, p. 9; February 1, 1913.

2. Opal glass reflectors. Sudan No. 01213 8 in. (20 cm.), Panalex design, dull finish used with form H holder. Mounted 9 ft. 9 in. (3 m.) from the floor to lower edge.
3. Art glass. Monolux No. 3,540 and 3,541. Mounted at 8 ft. 0 in. (2.4 m.) from floor to upper edge.
4. Opal glass semi-indirect. Calla No. 1,215 16 in. (41 cm.). Mounted 8 ft. 0 in. (2.4 m.) from floor to upper edge.
5. Totally indirect. X-Ray No. 14,270 mounted at 8 ft 0 in. (2.4 m.) from floor to upper edge.

Note.—XI 60 Prismatic and Sudan No. 01213 7 in. (18 cm.) reflectors were used with 60-watt bowl frosted lamps suspended 9 in. (23 cm.) from ceiling for low intensity direct system tests.

Eye Fatigue Tests.—A standing desk 6 ft. (1.8 m.) long by 3 ft. (0.9 m.) wide and having a mean height of 44 in. (1.1 m.) was placed facing toward the center of the room, with stool in position indicated. By arrangement an accountant of the treasury department did regular accounting work, principally extensions of books, under each of the five different schemes of illumination. His working day averaged about seven hours and he used each system for five days. Before starting work and at the close of work in both morning and afternoon periods, Ferree tests were made on his eyesight by J. R. Cravath, giving two pairs of tests per day or ten complete visual tests under each system.

Tests of Light Direction (Shadowgrams).—A new method was developed for recording shadows photographically—shown in Fig. 3. A plate holder loaded with Velox transparency film was supported in a 30 in. (76 cm.) horizontal plane at the station to be investigated, the lights turned off, the film exposed, a round vertical rod $^3/_{32}$ in. (2.3 mm.) in diameter and $1^1/_2$ in. (3.8 cm.) long standing on circular base $^3/_8$ in. (1 cm.) in diameter placed in the center of the film and the lights turned on for 30 seconds. Shadows thrown by the rod were recorded on the film. One end of the film previously protected was later exposed in the laboratory under fixed conditions, the tone of the print

from this end serving as a check to show that the chemical manipulation of all films was identical.

Intensity Measurements.—Eighty stations were laid out making each the center of a 28¾ in. (73 cm.) square. As preliminary surveys on a plane 30 in. (76 cm.) above the floor showed the four quarters of the room to be practically identical in horizontal illumination, the final tests were confined to this plane and to the twenty stations in a single quarter.

A Sharp-Millar photometer (standard size) was used exclusively. It was mounted on truck for quick movement from station to station, storage battery supply and ammeter reading being used to insure constancy of comparison lamp. The instrument was checked against standard lamp in the laboratory every two or three days and showed fair performance.

In the actual surveys four readings were taken at each station and the mean accepted as the actual value. A complete set of eighty readings could be taken easily in one half hour.

APPENDIX II.—SPECIFICATION COVERING .... BOWLS FOR SEMI-INDIRECT LIGHTING EQUIPMENT.

Quantity.—...... 20-inch bowls and ...... 16-inch bowls are to be furnished under this specification on Commonwealth Edison Company purchase requisition No. ....

Material.—Bowls are to be of special grade of .... glass manufactured by the .... under the trade name, ...

Design.—Bowls are to be etched with special Greek fret and central web as shown on sketch submitted by .... The upper edge of Greek border is to be 2½ in. below bottom edge of rim, and over-all width of border is to be 2¾ in. on 20-in. bowls. All measurements taken over the curving surface of the bowl. Central web of 20-in. bowls to be 7¼ in. in diameter. All three dimensions to be decreased proportionately for 16-in. bowls.

Etching Detail.—All etched lines to be smooth and of uniform depth. Greek border to be strictly parallel to edge of bowl. Variation in distance between support edge of bowl lip and upper edge of Greek border to be not more than $^1/_{16}$ in. in any given bowl and variation of average distance between support edge of bowl lip and upper edge of border of different bowls to be not

more than $^1/_8$ in. Central web to be centered within $^1/_8$ in. of center of circle outlined by lower edge of Greek border.

Etching details to be checked by measurement and inspection of a sample from each shipment comprising 5 per cent. of lot selected at random.

Surface Finish.—External surface to present uniform iridescent texture, free from scratches, lines or other blemishes. Internal surface to be highly polished, free from bubbles, bunches or other irregularities.

Twenty-inch Bowls (1. *Weight*).—Weight of 20-in. bowls on this order is to be within one pound of the average weight of the lot, that is, no bowl more than one pound heavier or one pound lighter than the average will be accepted. The limits of maximum and minimum weight thus established shall apply to all future orders for this style and size of bowl.

(2. *Over-all Dimensions*).—Each bowl to fit sample ring furnished. Outer diameter of lip to be 20 in. plus or minus $^1/_{16}$ in.

(3. *Thickness*).—Thickness of any given bowl to be so uniform as to permit even color tone over entire bowl when lighted by three or four symmetrically placed 100- or 150-watt Mazda lamps. Variation in average thickness of separate bowls to be within limits necessary to give close color tone match to standard bowl used to check previous shipments of 20-in. design ...... bowls.

(4. *Inspection by Customer.*)—Compliance of shipment with weight specification to be checked by weighing all bowls. Compliance with thickness specification to be checked by inspecting uniformity of color of each bowl when lighted by three 100-watt lamps, and by comparing this color with that of standard ...... bowl.

Sixteen-inch Bowls.—These ...... bowls to be of quality agreeing with the spirit of above specification for 20-in. bowls, necessary modifications being made in proportion to reduction of diameter.

(1. *Weight*).—Average to be specified after receipt of first one dozen bowls.

(2. *Over-all Dimensions*).—Each bowl to fit sample ring furnished.

(3. *Thickness*).—Thickness specification identical with that of 20-in. bowls except that 60- and 100-watt lamps shall be used.

(4. *Inspection by Customer*).—As outlined under 20-in. bowls.

Rejection of Imperfect Bowls.—If checks on samples as outlined above show breach of specification, entire shipment to be checked for detail in question and all bowls not in strict compliance with requirements to be rejected.

DISCUSSION.

Mr. F. A. Vaughn: I am anxious to utter a few words of commendation for work of this kind, especially the reference to the translucent bowls and the study of their characteristics and the attempt to discover luminous bowls which will satisfactorily meet the illuminating engineering requirements. This paper is particularly valuable, not only in its technical results and the highly satisfactory use of a particular type of glassware in a specific office, but in pointing out, as the authors have done, the almost utter lack of bowls which are satisfactory, if one wishes to have a choice. The choice of the illuminating engineer is undoubtedly restricted very greatly, in spite of the very great number of different types of glassware presented to him. Most of them are not satisfactory for this sort of work, and I hope that investigations of this kind will spur manufacturers on to making more dense, more esthetic and more beautiful glassware so that we will not be so restricted in our choice of units of this character.

Mr. W. R. Moulton: The authors are to be commended for the thoroughly practical data and information presented in this paper. It is of special value to the practical engineer who is daily confronted with similar problems.

The glass manufacturer is usually more interested in the production of a great number of bowls at a certain profit, than in the lighting result obtained from his glassware. This work in Chicago has impressed this particular glass manufacturer with the value of a complete study for the application of his product to illumination problems. This experience will undoubtedly improve his product in the future, and in turn assist in raising the general standard of all the manufacturers.

Fixture construction is an item of sufficient importance to

merit the engineer's consideration. Cooperation of the engineer with the fixture designer and manufacturer should result in a greatly improved product, without sacrificing any artistic effect. The work done by the authors proves this conclusively.

Mr. J. R. Cravath: You will notice that the authors have given figures on the brightness of the bowls as compared with the brightness of the backgrounds against which they are likely to be seen. The care taken to keep those ratios low represent some of the most important work done on this installation. In a report that has already been filed with the Council by this year's Committee on Glare, is the carefully considered statement that in the opinion of the committee the evidence so far indicates that contrasts of brightness in excess of from 1 to 100 to 1 to 200 are likely to produce "glare," that is manifested by eye fatigue or annoyance. You will notice that the figures given in the paper are well within that range. A point not fully appreciated heretofore, which I would like to emphasize, is that it is not so much the absolute value of the brightness of the globe as it is the brightness compared with its background that causes glare.

I can second what Mr. Vaughn has said as to the difficulty of getting sufficiently dense semi-indirect glassware. Most of the semi-indirect installations heretofore have not been properly engineered, if engineered at all. We need to give more attention to this point, the brightness of our semi-indirect bowls.

Mr. R. ff. Pierce: This paper is a particularly interesting one to me because, in the course of designing glassware fixtures for a line of semi-indirect lighting units which the company I am connected with placed upon the market about a year ago for use in connection with horizontal Bunsen burners, we undertook practically an investigation of the same considerations from a purely commercial standpoint. Mr. Durgin and his co-author have been fortunate, possibly, in that the results of their investigations were not required to be passed upon and endorsed by the general public, whereas the designs upon which we decided were subjected to the approval of the purchasing public; in other words, they were manufactured for sale, and in connection with this two or three considerations of considerable interest arise. It is noteworthy in the first respect that the design finally agreed

upon is substantially the same in both cases. We decided upon a bowl for lighting which has substantially the same characteristics of distribution as the one displayed here, but we found that the general public demanded higher intensities,—higher brightness in the bowl—than was exhibited in the glassware first used. In other words, people have not succeeded in getting it out of their heads that there is anything in illumination more important than getting an extremely bright piece of glassware, and that has been the greatest obstacle we have to overcome in raising the standard of illumination in the trade which we sell. The general public demand much higher bowl-brightness than are found to be satisfactory to discriminating observers. We found, for example, that those bowls which gave a brightness of four of five times and eight and ten times the brightness which we had fixed upon, were demanded by the majority of the consumers. The average consumer seems to be obsessed with the idea that all that is necessary to make a semi-indirect lighting fixture is a piece of glass more or less opalescent turned upside down. In some previous papers presented to this society, Dr. Ferree presented the results of an investigation in which he showed that with orders of surface brightness ranging above 0.1 candlepower per square inch, diffusing glassware of any character whatever was practically no better than a bare lamp, and with that in view, it appears to me that the general, broad claim that any type of semi-indirect lighting represents an improvement over unshaded lamps is misleading. Probably the indirect lighting systems possess a degree of brightness which makes them practically no better than bare lamps as far as the fatigue of the eye is concerned, and I think that some concerted movement to limit the degree of brightness to something of the order shown in this sample is highly desirable.

Mr. S. B. Burrows: There is one point in this paper which appeals to those of us who are interested in kilo-watt-hour sales as well as the application of the principles of illumination, and that is the point that at the present time both the central station and dealer talk in terms of candlepower.

It is no wonder that most of our customers are in the frame of mind Mr. Pierce speaks of, for there are any number of jobbers and electricians, in practically every town, selling gas-filled tung-

sten units indiscriminately as lamps, rather than illumination, neglecting accessories which would conform to or help the high intrinsic brilliancy of the unit. There is a field here which, it seems to me, for engineers is the biggest we have seen for sometime, namely increasing lighting sales in kilowatt-hours by pushing the sale of glassware which is admittedly best for the eye, thereby increasing the wattage in any one installation, and giving better illumination.

Those of us who are not only illuminating engineers but also salesmen should give more attention to the semi-indirect and indirect fixtures than we have heretofore given, if for no other reason than for those sales.

Mr. H. Thurston Owens: The sale of semi-indirect fixtures varies inversely with the size of the bowl. The smaller bowls are cheaper to make and easier to sell, and as this condition is at variance with the promotion of better lighting it will take the concerted action of the whole lighting industry to change the situation. Many of the so-called semi-indirect units are, in effect, direct lighting units and produce a glare quite as objectionable as the older forms of direct lighting.

Mr. W. A. Durgin (In reply): One point may bear amplification. We advocate a dense amber bowl, not primarily because it has high absorption and hence leads to the sale of more energy. We advocate it because we believe that the amber filtered flux gives the customer increased effectiveness of lighting far more than in proportion to the decreased utilization efficiency. The time has arrived when we can afford to throw away a part of the generated flux in order to secure higher effectiveness from the filtered remainder. The customer gets the advantage of better lighting in increased business, increased production, improved eye hygiene or esthetic satisfaction; the lamp manufacturer sells larger lamps, the fixture and glassware people sell semi-direct instead of small direct combinations and the central station maintains output.

THE APPLICATION OF CROVA'S METHOD OF COLORED LIGHT PHOTOMETRY TO MODERN INCANDESCENT ILLUMINANTS.*

BY HERBERT E. IVES AND E. F. KINGSBURY.

Synopsis: Crova's method of colored light photometry, which consists in the observation of the photometer field by monochromatic light of a selected wave-length, is one of the simplest and most practical means of facing the problem under those conditions where the method is applicable. Practical means for applying the method are here developed for the ordinary incandescent electric and gas illuminants. Calibrations are made on the basis of the authors' luminosity scale.

Lord Rayleigh[1] suggested in 1885 that the comparison of compound lights of somewhat different color might be facilitated by observing them by monochromatic light. He described a monochromatic telescope to be used for this purpose. Crova,[2] going a step further, suggested that such a monochromatic color of the spectrum be chosen so that the total luminous intensity of the lights under comparison would be represented by their relative intensity at this wave-length. He showed that, in the case of illuminants possessing continuous spectra, such a representative wave-length could be found.[3]

The advantages of the Crova method for eliminating color differences in photometric comparison are very real, and it is at first sight strange that it has not been more generally employed. The reason is not far to seek, however. Like all other means for eliminating color differences at the photometer, Crova's method must be calibrated in terms of some accepted luminosity scale. The ability to make a perfectly definite setting agreeing with the setting of any other observer is, in the majority of cases, of no

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

[1] Rayleigh, A Monochromatic Telescope, with Application to Photometry ; *Phil. Mag.*, June, 1885.

[2] Crova ; *Comptes Rendues*, 93, p. 512.

[3] Ives, Note on Crova's Method of Heterochromatic Photometry; *Physical Review*, March, 1911.

value unless one knows what value to give to that setting. In the case of Crova's method this means that one must have some definite proof that the wave-length employed is the representative one or else know how much it over or under-evaluates the intensity of those light sources which are of interest.

In searching for the most practical method of colored light photometry for use in a gas photometric laboratory, we have recently experimented with Crova's method with very satisfactory results. The problems of gas mantle photometry are somewhat peculiar. There exists a wide range of color in mantles of different composition and structure, added to which are smaller differences caused by variations of adjustment of the burner and by changes in the kind of gas used. These differences cannot be taken care of by the mere change in concentration of a color-matching solution, as in the case of the Fabry solutions as worked out for the electrical illuminants.[4]

There are several different requirements to be met in the practical development of means for carrying out Crova's idea, which are in partial conflict. The dominating practical requirement is that the means for securing monochromatic light shall not be prohibitively wasteful of light. This practically means that a compromise must be made between the purity of the monochromatic light and the working illumination.

A second point, governed in part by the one just emphasized, is that different parts of the spectrum are differently suited for securing monochromatic light with maximum quantity. Thus, the hue of the spectrum changes very rapidly in the yellow, so that there a very narrow band must be chosen in order to eliminate color differences. On the other hand, in the green region hue change is slow, and a comparatively wide band of the spectrum may be used, with consequent increase of light. Finally comes, of course, the restriction that the true representative or Crova wave-length has no connection with the luminosity or hue considerations. It actually happens that the Crova wave-length lies in the yellow, where hue change is rapid. Thus there is as one alternative working for the most complete elimination of color difference, using a wave-length in the green, and determining its

[4] Ives and Kingsbury, Experiments with Colored Absorbing Solutions for Use in Heterochromatic Photometry; TRANS. I. E. S., p. 795, 1914.

calibration; and as another alternative working for perfection of color difference elimination in favor of the convenience of the true Crova wave-length. Actually, as will be seen, still other considerations have had a say in our particular problem.

To obtain monochromatic light Crova used a solution of nickel nitrate and ferric chloride, placed between the eye and the photometer. After some study of colored glasses we have decided in favor of the use of a solution, similar in properties to the one used by Crova, as being more definitely reproducible and as being more nearly monochromatic. Our first work was done upon a monochromatic green solution, which had been developed for another purpose,[5] our idea being that its excellent monochromatic quality would outweigh its non-agreement with the Crova wave-length. The transmission of this solution, whose composition is:

CuCl	265.0 grams
$K_2Cr_2O_7$	2.5 grams
HNO_3 (1.05 gr.)	26.5 c.c.

Water to 1 liter of solution at 20° C.

was measured in a thickness of one centimeter, against a clear

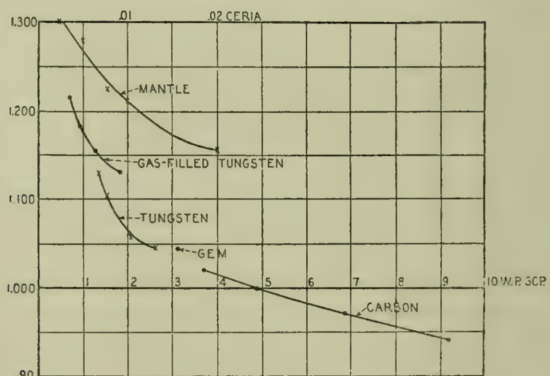


Fig. 1.—Transmission of monochromatic green solution with various illuminants, in times of its transmission of the light of a "4-watt" carbon lamp.

water solution, by means of our physical photometer,[6] which incorporates the characteristics of our average eye. The results with various illuminants, all expressed in terms of the standard

[5] Ives and Kingsbury, Flicker Photometer Measurements by a Large Group of Observers on a Monochromatic Green Solution; *Physical Review*, March, 1915, p. 230.

[6] Ives and Kingsbury, Physical Photometry with a Thermopile Artificial Eye; *Physical Review*, 1915.

"4-watt" carbon lamp, are shown in Fig. 1. The abscissae are watts per mean spherical candle, in the case of the electric lamps, and proportion of ceria, in the case of the mantles, the mantles used being of a representative weave and weight.

For our purposes this solution was decided not to be suitable, the chief reason being that the mantle values lie on a line which is altogether too steep. While the values are given in terms of mantle composition, the color is as well a matter of weight and weave and of burner adjustment. Variations of any of these factors, such as are to be expected in miscellaneous testing, were found to be equivalent to running up and down on the curve by an amount of several per cent.

Our experience with this solution led us to formulate a new criterion for our own work in mantle photometry, namely, that the monochromatic solution to use is one which has as nearly as possible the same transmission for all the ordinary gas mantles, irrespective of what it might be for other illuminants. We would then be as free as possible from the effects of the variables peculiar to that kind of photometry.

Using the physical photometer a process of trial and error was gone through with the relative proportions of the two coloring constituents of the solution being gradually changed so that the equivalent wave-length moved toward the yellow. A solution was finally obtained which answered to the requirements, whose composition is as follows:

$CuCl_2$	90.0 grams
$K_2Cr_2O_7$	30.0 grams
HNO_3 (1.05 gr.)	40.0 c.c.

Water to 1 liter of solution at 20° C.

This solution is to be used in a thickness of 25 millimeters.

A calibration of this solution was carried through with the physical photometer, not only for the mantles but for all the common electric and flame illuminants. This calibration is shown in Fig. 2, by the crosses.

Supplementary to this a partial calibration was made by the visual methods developed by us; for while we have established the agreement of the visual and physical methods with great care it was thought worth while to take this opportunity to make a further check. We first made a set of observations by the flicker

method, under the standard conditions, selecting our observers according to the scheme recently described before the Society.[7] The procedure was to have each observer make a set of readings with an ordinary Lummer-Brodhun head, interposing the Crova solution between eye and eye-piece. The eye-piece was then

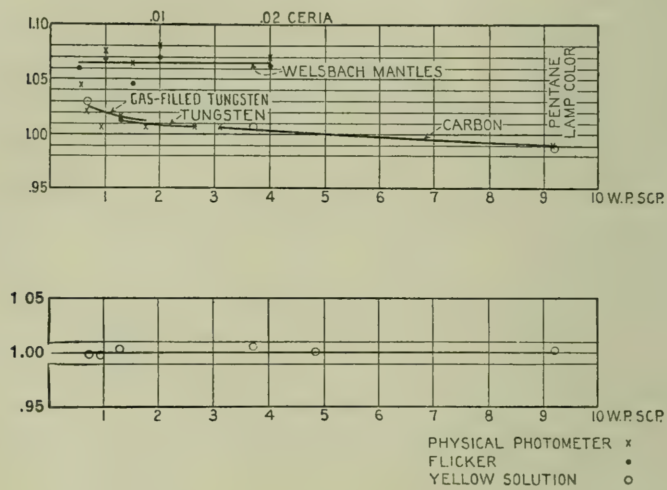


Fig. 2.—Transmission of Crova solutions in times of transmission with "4-watt" lamp. Upper—gas solution; lower—electric solution.

removed and the flicker photometer attachment[8] put in its place, and another set of readings made. Both sets were made against a "4-watt" lamp. Under these conditions all questions of the slight change of transmission of the solution with temperature, etc., are ruled out. The flicker photometer points are shown by dots.

In addition to the flicker settings a check was made upon the electric illuminants by the use of the Fabry yellow solution recently described,[9] whose calibration was done by the same flicker method, but by a different group of observers. The values

[7] Ives and Kingsbury, On the Choice of a Group of Observers for Heterochromatic Measurements; TRANS. I. E. S., No. 3, p. 203, 1915.

[8] Kingsbury, E. F., A Flicker Photometer Attachment for the Lummer-Brodhun Photometer Head; *Journal of the Franklin Institute*, August, 1915.

[9] Ives and Kingsbury, Experiments with Colored Absorbing Solutions for Use in Heterochromatic Photometry, TRANS. I. E. S., p. 795, 1914.

assigned to the Crova solution by the Fabry solution are shown by the circles.

It is evident that our various means of calibration are in excellent agreement, and that we have a solution meeting our criterion, that the incandescent gas mantles should measure alike.

Upon the completion of the work on the mantle solution, it seemed worth while to determine what solution would answer the same purpose for the incandescent electric illuminants. By a slight change of the relative proportions of the constituents such a solution was found, as follows:

$CuCl_2$	86 grams
$K_2Cr_2O_7$	60 grams
HNO_3 (1.05 gr.)	40 c.c.

Water to 1 liter of solution at 20° C.

The calibration of this solution was carried out entirely with

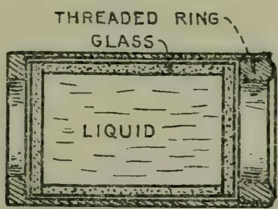


Fig. 3.—Cell for holding Crova solution.

the aid of the Fabry yellow solution. It is shown in Fig. 2 (lower diagram). The transmission is practically the same over the whole range of lamp colors from the color of the pentane flame to that of the high efficiency nitrogen-filled tungsten.

For the practical use of these solutions we have devised a small absorption cell which slips into the eye-piece of the Lummer-Brodhun photometer head. It is shown in section in Fig. 3. The solution is held in a glass cell consisting of a section of glass tubing on which plane glass ends are fastened with paraffin. This cell is then imbedded in the brass casing with plaster of Paris, the excess being squeezed out when the threaded ring is screwed into place. We have thus far had no trouble with any leakage from these cells.

The procedure in using the solutions is quite simple. In our laboratory the gas solution is of course used, except in special work. Every photometer head is permanently equipped with its

solution cell. All the standard lamps have their efficiencies tabulated on a card near the photometer, beside which is a blue-print of Fig. 2. The operations are exactly as in ordinary photometry, but the resultant values are to be reduced in accordance with the ratio indicated by the chart. We have, however, introduced a still further simplification by tabulating the "Crova solution value" of each standard, which is simply the value to be assigned to it in order that the readings on the mantles shall be in their correct values as obtained. The Crova value of a 4.85 w. p. s. c. p. carbon standard, for instance, is $\frac{1}{1.065} \times$ its true value.

In the case of the electric solution no correcting values are necessary; observations are made and recorded as though no solution were present. Its use is, however, restricted to incandescent electric illuminants.

Our experience thus far with this method has been very satisfactory. The very slight color difference which remains we find to give no trouble, while the loss of light (the transmission is about 10 per cent.) is taken care of by more careful shielding of the observer's eye, and taking greater care to avoid looking at the light source. The precision of setting is practically the same as in ordinary photometry of lights of the same color. The greater convenience of this method over those requiring a change of absorbing medium with each change of illuminant makes it by far the most practical laboratory means for eliminating color differences.

The calibrations here given are in terms of the luminosity scale developed and used in our laboratory. Should any other consistent scale be ultimately adopted, slight changes in the relative proportions of the constituents of these solutions would fit them to perform the same function in conformity with such scale.

Fig. 4 shows the spectral transmission of the two solutions, and in Fig. 5 these same transmissions are shown multiplied by the energy distribution of a tungsten lamp and by the luminosity curve of the eye. The resultant curves show (by calculations of their centers of gravity) that the equivalent wave-lengths are approximately 0.573μ for the mantle, and 0.577μ for the electric solution.

While we have obtained our monochromatic light by the use of absorbing media it is worthy of note that a very elegant method would be by the use of a spectroscopic eye-piece, similar in principle to Lord Rayleigh's monochromatic telescope, to take the place of the ordinary photometer eye-piece. Such a device would permit the variation of the wave-length used and also, by varying the width of the slit, of the amount of light, to suit the con-

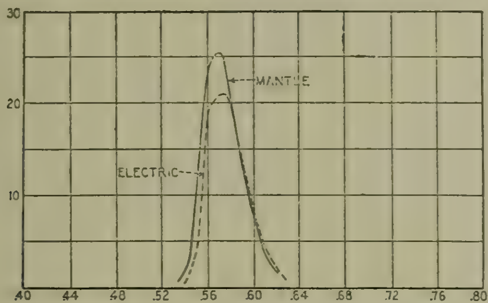


Fig. 4.—Spectral transmission of Crova solutions.

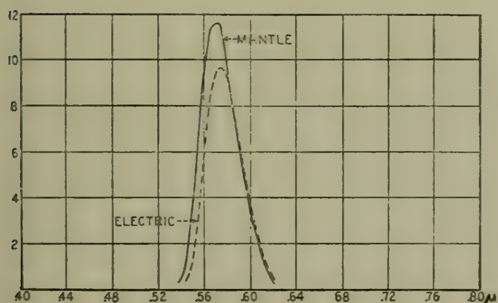


Fig. 5.—Spectral transmission of Crova solutions, multiplied by typical illuminant energy distribution and visual luminosity curve.

ditions. The calibration of this kind of instrument could not be done at present with the physical photometer, which would not be sensitive enough, but the alternation of the flicker attachment and a spectroscopic attachment in the manner described in connection with the Crova solution, furnishes an excellent means for calibrating such an eye-piece. It, of course, involves the use of a group of observers, but with the equivalent wave-length closely determined by the present work, the labor of finding this exactly should not be great.

DISCUSSION.

DR. P. G. NUTTING: If it is in order, I would like to ask a few questions about the method rather than the matter presented here. Do I understand, Dr. Ives, that you are entirely independent of the observer? Are your intensities read as deflections of a galvanometer needle? I should also like to ask what the sensibility of the method is, the amount of probable error, etc; what is the range over which it is applicable under the conditions described?

DR. C. E. K. MEES: I should like to ask Dr. Ives what the stability of the solution is, and what means he takes to check it. It strikes one who has been trained as a chemist, off hand, that a bichromate and nitric acid would form a powerfully oxidizing solution, and if there is any possibility of its oxidizing anything it will do it; so it would be necessary to obtain some analytical check on the solution.

M. LUCKIESH: I should like to ask Dr. Ives if he has had an opportunity to test the permanency of this solution over a period of a few months or more. If it is permanent it will be of considerable advantage.

DR. H. E. IVES: Regarding stability,—strictly speaking, the answer depends upon the time more than upon any definite evidence we can offer. We simply say this, that the constituents were the same as ones used in a previously developed solution, on which many tests for permanency were made, and that during the time that this work was continued, we watched very carefully and made photometric checks of one sort and another which would, we believe, have revealed any change in composition or behavior. Now if you will note, from the figure showing the construction of the containing cell, the solution is in contact with nothing except glass, with the possibility of a very thin edge of paraffin, so that the possibility of its doing any oxidizing is negligible. The cells have not shown any leakage. I think now it is about four or five months since our set of tanks was put in use. We very recently made a check of the results obtained by their use, against our physical photometer, and the check was absolute. We have noticed some temperature coefficient of change of transmission, and thought we noticed some reversible photochemical change. For instance, we did part of the work with

large tanks which were exposed directly to radiation from the light source. We obtained some results which seemed to indicate that if this solution were exposed to light continuously for a long time, its transmission would alter somewhat. On being let alone in the dark for a few hours, the solution returned to its original state. In all the later work the solution was used exclusively in the eyepiece, where the intensity of incident radiation is very small, and any change would effect both sides of the field practically the same.

Mr. Mees: Does it get yellower?

Dr. Ives: Yes, it probably did. I do not remember exactly, but all these changes which we have suspected are minimized in their action by the method of use. If there is a change in the total transmission without a shift, both illuminants are affected equally. If there were a very large shift, that would be serious, but we have not found any. I realize that this is not an adequate answer to the general question of stability. If we had had these in use for two or three years, we could, of course, give more definite information, but I will say that we have found them satisfactory and perfectly consistent with such checks as we have made by going around the complete circle at various periods.

In regard to Dr. Nutting's question, whether the method is independent of the observer—of course, if we had an absolutely monochromatic solution or used a spectroscopic attachment with a sufficiently narrow band of transmission, we would be quite independent of the observer. (The transmission of a solution much more monochromatic than the one described would probably be prohibitively low.) On a recent test of some incandescent lamps which I mentioned a minute ago, in abstracting the paper, we deliberately chose two observers from our laboratory, one of whom I think is the most blue sensitive of any we have, and a rather red sensitive one. These two observers made the observation and there were no systematic differences of any sort. I think I am justified in saying that unless a very abnormal observer is used, the method is independent of the observer.

Dr. P. G. Nutting: You do measure light rather than energy.

Dr. Ives: Yes; this is a visual method. Now as to precision: using the photometer as we do with laboratory voltmeters, and

as a common battery we are working to probably less precision than that of a laboratory such as the Bureau of Standards, where they may have a whole storage battery for one particular investigation, and it is very probable that the effect of even the slight color difference still present would show itself on a long series of tests in somewhat lower precision. But for our purposes, the precision is all that could be desired. The range of applicability is just so far as shown on these curves. It may be further, but we do not so state.

COMPENSATED TEST-PLATE FOR ILLUMINATION PHOTOMETERS.*

BY CLAYTON H. SHARP AND W. F. LITTLE.

Synopsis: The errors of illumination test-plates due to their deviation from the theoretical cosine law have been studied experimentally (Tables I, II, III, IV, Figs. 1 and 2). The most important cause for the deviation of test-plates from the cosine law is shown to be the increasing reflection with increasing incidence according to Fresnel's law (Fig. 3). Test-plates may be compensated for the deficiency in brightness with light at large angles of incidence by admitting light to the posterior side of the plate in sufficient quantities. Transmitting test-plates are mounted on flashed opal rings of suitable width and light at 90° is cut off by a metal screen (Figs. 4 and 5). Reflecting test-plates are constructed as in Fig. 6. The results of this method of compensating plates are shown in Tables V and VI and are summarized in Fig. 7. The results of a test of illumination with compensated and uncompensated test-plates are given in Table VII. The possible application to the integrating sphere is noted.

The only essential difference between a photometer for the measurement of illumination and a photometer for the measurement of candlepower is that the illumination photometer is provided with a photometric surface or test-plate which should vary in brightness as the cosine of the angle of incident light. The test-plate, which serves as a device for integrating the luminous flux falling upon it, is the distinguishing feature of the illumination photometer. Any failure on the part of the test-plate to integrate correctly is reflected in corresponding errors in the results of the illumination measurements. This paper contains a discussion of errors encountered in existing forms of test-plates due to departure from Lambert's cosine law, and a description of a method of compensating the test-plates in order to avoid such error.

Classification of Test-plates.—Test-plates may be divided into two general classes according to the method of their use:

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(*a*) Transmitting (usually attached to the photometer).

(*b*) Reflecting (usually detached from the photometer).

Transmitting plates are made of diffusing glass usually depolished on the exposed surface. Reflecting plates may be of opaque material having a diffusing surface, or they also may be of depolished white glass.

Historical.—Unfortunately there is no known substance nor method of constructing a surface which obeys the theoretical cosine law of Lambert. Wright, some fifteen years ago, succeeded in making surfaces of compressed powders which came very near it; but evidently this form of construction would not lend itself to the practical requirements of photometry. Therefore photometrists in measuring illumination have been obliged to content themselves with test-plates which were known to give erroneous results under conditions of high angle of incidence. The comforting thought, however, was always present that probably in the great majority of cases the light flux incident at high angles represented so small a percentage of the total flux that an error in measuring it was relatively of little consequence. Nevertheless, the test-plate error has been by all means the largest intrinsic or unavoidable error in illumination measurements, and the knowledge of its existence has been a thorn in the flesh of photometrists. Therefore no little study has been given to the question of a practical method of its avoidance.

The idea of replacing a material surface by an imaginary one, such as a clear aperture in an opaque body, undoubtedly has occurred to more than one worker in this field. Such an aperture would evidently transmit light in accordance with the cosine law, but unfortunately it would require some auxiliary arrangement to diffuse this light. A small aperture in the surface of an integrating sphere would admit flux of light proportional to the cosine of the angle of incidence, and the flux density at a point in the interior of the sphere, which is shielded from the aperture, would measure the flux admitted. Evidently such an arrangement must have its limitations in practise, because of the practical limits of the size of the sphere and because the loss of light involved in the multiple reflections required in diffusing the light, will be so great that the field viewed in the photometer will be of

relatively feeble intensity. A construction along these lines, the details of which however are not entirely clear from the meager account at hand, has been described by Bechstein[1] before the German Illuminating Engineering Society. He states that with the aperture in the sphere one forty-sixth as large as the surface of the sphere itself, the cos i error at 70° incidence is —6 per. cent., and the brightness of the field is one third as great as that of a plaster of Paris plate with the same illumination. Evidently if the advantages so noted are not over-borne by disadvantages which are not mentioned, this style of test-plate marks a decided improvement.

W. D'A Ryan patented a form of test-plate some five years ago which was intended to obviate the cos i error. This test-plate consisted of a block of diffusing glass with a dome-shaped upper surface for the reception of the illumination. Surrounding this surface was a low circular screen notched at the top in such a way that the shadow cast by it on the surface was sufficient to maintain the diffused flux of light in the interior of the block at its right value with i approaching 90°. The dome-shaped upper surface evidently tended to correct the deficiency of brightness at high angles by presenting a larger surface to illumination at those angles. This, of course, gave a lopsided distribution of light on the test-plate, but the thickness of the plate was such that the flux was undoubtedly fully diffused before it reached the photometric field. It would seem that there must have been a very serious loss of light in passing through this thick diffusing test-plate. The device was incorporated by Mr. Ryan in an illumination photometer.

Study of Test-plate Errors.—It may be advisable next to study the errors[2] of existing test-plates such as are commonly used in

[1] *Zeitschrift für Beleuchtungswesen*, March 15, 1915, p. 31.

[2] The apparatus used in the study of test-plates was as follows: The telescope was removed from a spectrometer and to the arm of the spectrometer a light tubular support was attached, carrying at its outer end an incandescent lamp enclosed, except for a slit in front, by a metal screen. The radius of the circle in which the lamp moved was about one meter. Transmitting test-plates to be studied were fixed to a portable photometer and adjusted at the center of rotation. Reflecting test-plates were entirely detached from the photometer which then was set up at such a distance that the arm carrying the lamp could be moved in front of it. The angles were accurately read on the divided circle of the spectrometer. With high angles of incidence it is necessary that the angle shall be measured quite accurately inasmuch as the values of the cosine are changing rapidly.

order to inform ourselves as to how serious they are. In Table I are given variations from the theoretical values shown by two transmitting test-plates of white glass with the surfaces depolished. It will be seen that while the error is of relatively small magnitude up to about 40°, yet beyond that point it becomes quite serious.

TABLE I.—ERRORS OF TRANSMITTING TEST-PLATE WITH DEPOLISHED SURFACE.

Plate numbers	5	220
Thickness (inches)	0.0718 (1.82 mm.)	0.055 (1.4 mm.)
Angle of incidence	Errors, per cent.	
0°	0	0
10°	+ 0.5	+ 0.5
20°	0	0
30°	— 1.5	— 2.5
40°	— 5	— 4.5
50°	— 8	— 7
60°	— 8	—10
70°	—13	—13
80°	—24	—29
85°	—33	—37

In the use of reflecting test-plates a complication enters which is not present with transmitting test-plates, and which arises from the fact that the reflecting test-plates are usually detached from the photometer, and the angle at which the photometer views the plate is not fixed; nor is the position of the photometer with respect to the direction of the principal flux of light reaching the test-plates; *i. e.*, the angle of azimuth. Hence a double dissymmetry. A transmitting test-plate attached to the photometer is viewed normally; hence the brightness of the plate must be independent of the azimuth of the incident light. The same thing is true of the reflecting test-plate, provided the grains of its upper diffusing surface are indifferently arranged and provided the plate is viewed normally. Ordinarily such test-plates are viewed with the photometer held in the hand, and the angle of view may differ from the normal by a considerable amount, while the azimuth is determined by the convenience of the operator. The arrangement therefore is not symmetrical with respect to the photometer.

The data on reflecting test-plates here presented do not represent a complete investigation but are sufficient for the purpose of showing some of the peculiarities encountered. Table II shows

TABLE II.—ERRORS OF REFLECTING TEST-PLATE OF DEPOLISHED WHITE GLASS.

	In plane of incidence				
Angle of view . .	0°	30°		45°	
Angle of Incidence		Same side	Opposite side	Same side	Opposite side
	Errors per cent.				
0°	0	0	0	0	0
10°	—0.5	+0.5	0	—0.5	0
20°	—1	0	+1	0	+ 1
30°	—2	0	0	+0.5	+ 8.5
40°	—2	0	+1	—1	+ 9
50°	—2	—0.5	+0.5	—0.5	+12
60°	—4.5	—1	+2	0	+20
70°	—7.5	+0.5	+1	—0.5	+29
80°	—9	—6	+7	—12	+44
85°	—11	—7	+19	—15	+59

the errors of a depolished white glass reflecting test-plate when viewed at 0°, that is normally, at 30° and at 45° all in the plane of incidence of the light. It will be noted that at 0°, which is the symmetrical position, the error at 70° is —7.5 per cent. When the angle of view is changed to 30°, a surprising thing is seen; namely that in the plane of incidence the errors of such a plate are small all the way to 80°. And this is true irrespective of whether the source of light illuminating the plate is on the side toward the photometer or on the side away from it. When the angle of view is increased to 45°, this symmetry vanishes. As in the former case, from 0° incidence to 90° incidence on the side toward the photometer, the errors are negligibly small. On the opposite side, however, the errors mount rapidly after 20° is passed until at 70° the error is +28 per cent. (see Fig. 1). This indicates a condition of specular reflection, which enters when the angle of view is as large as 45°, which is necessarily no factor when the light is on the side of the plate toward the photometer. In order to investigate this effect of the angle of view more closely, the readings shown in Table III and in Fig. 2 were taken. Here the angle of incidence of the light was maintained at 60° and the angle of view of the photometer was varied.

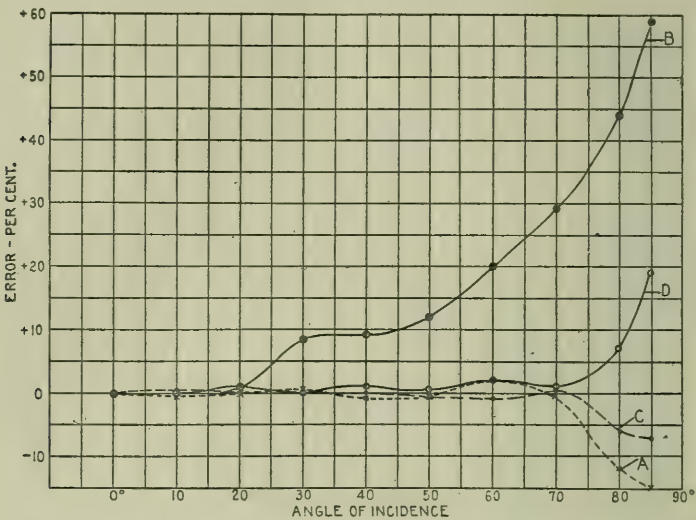


Fig. 1.—Reflecting test-plate, viewed in plane of incidence. A. Viewed at 45°; lamp on side toward photometer. B. Viewed at 45°; lamp on side away from photometer. C. Viewed at 30°; lamp on side toward photometer. D. Viewed at 30°; lamp on side away from photometer.

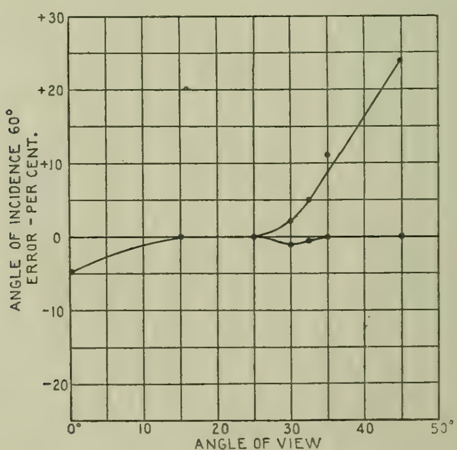


Fig. 2.—Reflecting test-plate viewed in plane of incidence. Angle of incidence = 60°. The upper branch of the curve beyond 30° shows the errors when the lamp is on the side opposite to the photometer. On the same side as the photometer the errors are practically zero.

It will be seen that the arrangement shows symmetry up to 30° angle of view and that at 25° and 30° angle of view, the error is zero. Above this point the errors increase when the lamp is on the side opposite to the photometer, whereas when the lamp is on the same side the errors remain negligibly small.

TABLE III.—ERRORS OF REFLECTING TEST-PLATE OF DEPOLISHED WHITE GLASS WITH CONSTANT ANGLE OF INCIDENCE AND VARYING ANGLE OF VIEW.

Angle of incidence = 60°.

Angle of view	0°	15°	25°	30°	32.5°	35°	45°
	Errors						
Same side	—4.5	—0.5	0	—1	—0.5	0	0
Opposite side	—4.5	0	0	+2	+5.0	+11	+24

TABLE IV.—ERRORS OF REFLECTING TEST-PLATES.

	In plane of incidence				At right angles
Angle of view	0°	15°	30°		30°
			Same side	Opposite side	
Angle of incidence	Errors, per cent.				
0°	0	0	0	0	0
10°	— 2.5	0	— 0.5	— 0.5	+ 0.5
20°	— 3.5	0	+ 0.5	0	0
30°	— 3	0	0	0	0
40°	— 6.5	+ 0.5	— 1	+ 1	+ 0.5
50°	— 9	— 2	— 1	— 0.5	— 1
60°	—11	— 2.5	0	0	— 6
70°	—15	— 7	— 7	0	— 7
80°	—23	—13	—14	— 3	— 8
85°	—25	—20	—24	— 3	—18

Data on tests of a commercial test-plate of other manufacture than the one given above are shown in Table IV. Here again the errors are smaller with an angle of view of 30° than they are at 0° or 15°. In a further study of this plate the photometer was placed so that its angle of view should be 30° to the plate at right angles to the plane of incidence to the light. The errors under this condition are given in the last column of Table IV. In these data as well as in the data of the preceding two columns, one finds a very good argument for the proposition that a test-plate of this character should be viewed at an angle of about 30°. A certain amount of dissymmetry is evident but it occurs at such high angles that it may not be a very important factor.

Causes of Deviations from Cosine Law.—It will be noted from the foregoing that in all cases where the test-plate is viewed from a symmetrical position, that is, along the normal, the test-plate errors are negative at the higher angles. The light incident at higher angles does not bring the brightness of the plate up to its theoretical value. More light is needed for this. It is interesting to inquire into the cause for it.

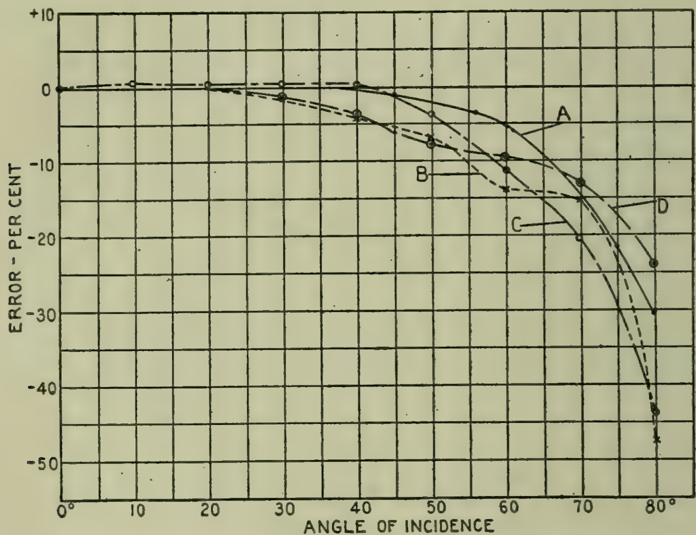


Fig. 3.—A. Reflection from polished glass, $n = 1.5$, reduced to zero reflection at normal. B. Errors of polished white glass test-plate. C. Errors of polished white glass test-plate. D. Errors of depolished white glass test-plate.

All the light incident on a test-plate is either reflected, absorbed or transmitted. In the case of a transmitting test-plate the brightness evidently cannot obey the cosine law, even if the glass itself is a perfect diffuser, unless the loss by reflection is constant for all angles. The endeavor is made by depolishing the glass to attain this condition. The reflection of a polished glass surface at various angles of incidence is shown in Fig. 3, curve A, in such a way that the values are comparable with test-plate errors in the tables; that is, all values are diminished by the percentage reflected at normal incidence, 4 per cent. If we were to use as a transmitting test-plate a disk of polished white glass, there would evidently be an error of 30 per cent. at 80° due to surface

reflection, quite apart from any failure of the glass to diffuse the light penetrating it. The actual errors of test-plates made of polished instead of depolished glass are shown for comparison in Fig. 3, curves B and C. These curves are evidently what would be expected if an imperfectly diffusing surface were overlaid with a smooth glass surface. The lack of diffusion is evidently less important as a source of error, than the variable loss by reflection.

In curve D of Fig. 3 are shown graphically the errors of depolished plate No. 220. It will be seen that the effect of roughening the surface of the glass is to diminish the loss of light at the higher angles and hence to improve the plate at these angles. That a variable loss by reflection still plays a part, however, is demonstrated by the fact that the light reflected at about the polarizing angle (56°) still shows, when examined through an analyzer, a considerable percentage of polarization.[3] It would appear therefore that the loss by reflection, following the theoretical law of Fresnel, may be considered as the chief cause for the deficiency of test-plate brightness at high angles.

PRINCIPLE OF COMPENSATION.

If additional light could be introduced to the plate, so proportioned as to be zero at normal incidence and to increase rapidly from 50° on, this deficiency might be overcome and the test-plate caused to give a correct result. It is this idea which underlies the compensated test-plate, forming the subject of this paper. The construction is a very simple one. In the transmitting test-plate the ordinary glass plate instead of being mounted on the end of a metal tube is mounted on a little diffusing (opal) glass ring. The brightness of the test-plate with 0° incidence is not altered by the presence of the opal ring except by internal reflections, but as the incidence increases, a larger and larger amount of light falls upon the ring, and by it is diffused in such a way as to add a certain illumination to the under surface of the test-plate.

[3] It is clear that in measuring partially polarized light (*e. g.*, skylight) the error of the test-plate will depend on the relation of the plane of polarization to the plane of incidence. This may be important in the case of reflecting test-plates. Furthermore, photometers operating on the polarization principle may give erroneous results with a reflecting test-plate of depolished glass or similar material such as celluloid. Such an error may be eliminated by taking settings with the polarizing apparatus in two positions at right angles to each other.

By properly proportioning the transmission of the test-plate and the transmission and diffusion of the ring, together with the width of the latter, a compensation for the deficiency in brightness of the test-plate at high angles may be obtained.

It is evident that if the arrangement as described were used, light coming at 90° of incidence, which would produce no illumination whatever on the upper side of the plate, would pass through the opal glass ring and illuminate the under side of the plate. Light coming from angles even greater than 90° might have the same effect. Evidently this light must be cut off and this is done by the interposition of a saucer-shaped screen with the edge of the saucer in line with the top of the aperture in the opal ring. The construction used is shown in half-section in Fig. 4, and the actual test-plate as attached to a photometer is shown in Fig. 5.

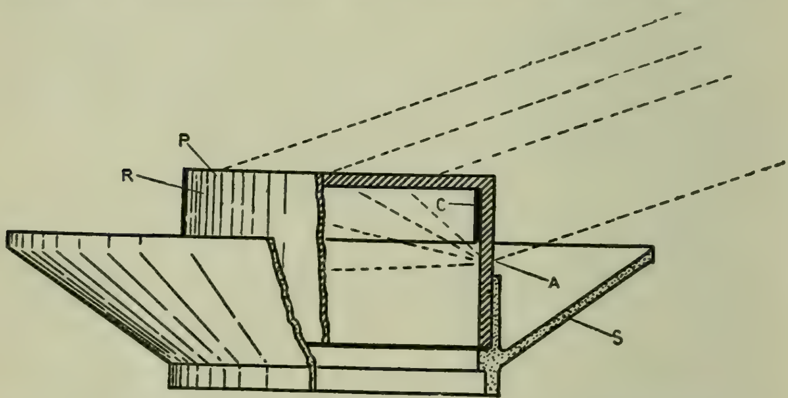


Fig. 4.—Compensated transmitting test-plate. P. Test-plate of polished white glass. R. Ring of opal glass. C. Opaque shield. A. Clear aperture in ring for admission of light. S. Screen to cut off light at 90° incidence.

It has been found that if the light is admitted to the opal ring close to the test-plate, the compensating illumination is not uniformly distributed over the test-plate, so that at high angles of incidence the field is irregular. On this account the aperture in the ring is placed well below the test-plate. The portion of the opal ring through which light should not pass is covered up by a metal band, the width of which determines the width of the aperture in the compensating ring and hence the amount of compensating light.

Evidently the amount of compensating light has to be accurately proportioned to fit the peculiarities of the test-plate. If the test-plate is quite thin and transparent, a larger amount of compensating light is required than if it is relatively dense. The more perfect the diffusing qualities of the test-plate, the less compensating light is required. It has been found in practise that the opal ring may be optically quite thin; that is it may be clear glass with a light flashing of opal. A ring of this character associated with a polished test-plate gives a combination which is quite

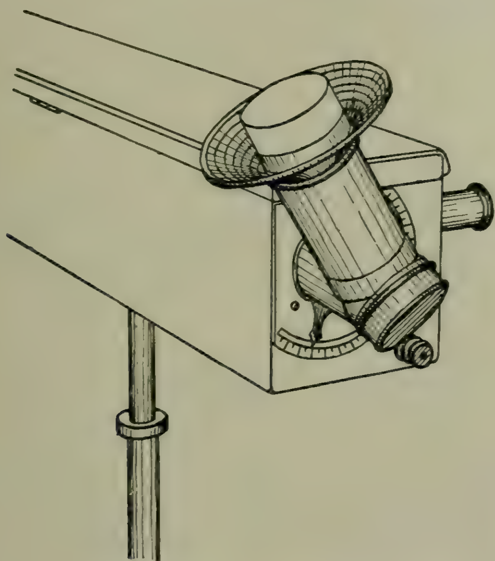


Fig. 5.—Compensated test-plate in practical form.

readily adjusted by varying the width of the annular aperture in the ring to conform with the cosine law even at very high angles of incidence.

Polished Versus Depolished Plates.—There are very considerable advantages accruing from the use of polished test-plates rather than depolished ones. In the first place a polished plate is more uniform in its characteristics than the depolished one and hence is more easily compensated for its error. The depolished plate varies according to the means used in removing the polished surface whereas the polished plate is not subject to this source of

irregularity, provided the polish is made sufficiently good. Furthermore depolished plates are very difficult to clean; minute quantities of dirt become embedded in the irregular surface and cannot be removed, while polished plates offer no difficulties whatever in this respect.

Results of Compensation.—In Table V are given the results

TABLE V.—TRANSMITTING TEST-PHASE OF POLISHED GLASS WITHOUT AND WITH COMPENSATING RING OF FLASHED OPAL.

Angle of Incidence	Plate B uncompensated	Plate B undercompensated $^5/_{32}$ in. (4.0 mm.) aperture	Plate B compensated $^3/_{16}$ in. (4.8 mm.) aperture	Plate A uncompensated	Plate A compensated	Plate A compensated in permanent mounting
	Error, per cent.					
0°	0	0	0	0	0	0
10°	+ 0.5	— 0.3	+0.5	0	0	0
20°	+ 0.5	0	0	0	0	0
30°	+ 0.5	— 0.5	—0.5	— 1.5	—0.5	+ 0.5
40°	+ 0.5	— 0.5	+0.5	— 4	+0.5	+ 1.5
50°	— 3.5	+ 0.5	—0.5	— 6.5	—0.5	+ 1.0
60°	—11	0	0	—13.5	—0.5	+ 1.5
70°	—20.5	— 2.5	+1	—15	—1	0
80°	—44	—13	+1	—48	—1.5	— 0.5
85°	—72	—11	+6	—	—4	—11

obtained in compensating two different plates. In the first column are shown the errors of an uncompensated polished plate; in the second column are shown the errors when this plate is undercompensated, the aperture in the opal ring being too narrow. In the next column are shown the results of a perfect compensation with the opening in the aperture of the ring only $^1/_{32}$ in. (0.8 mm.) wider than in the preceding case. In the next column another uncompensated plate is shown followed by results of the same plate compensated. In the last column are shown the errors of a compensated test-plate in practical form for using on the photometer. Remembering that measurements made at 85° of incidence are subject to large errors due to the great effect of small inaccuracies in the measurement of the angle and to the relative darkness of the field, it may be said that in all cases the outstanding errors are within the errors of observation.

Compensated Reflecting Test-Plate.—The construction whereby reflecting test-plates may be compensated in accordance with the above-mentioned principles is quite as simple as that of the

transmitting test-plate. The reflecting test-plate proper is made of a disk of depolished white glass; parallel with this disk is placed another similar disk. A similar opaque screen is used for shielding the upper disk from light coming at angles of 90° and

TABLE VI.—COMPENSATED REFLECTING TEST-PLATE. VIEWED NORMALLY.

Angle of incidence	Error, per cent.
0°	0
10°	— 0.5
20°	— 1.5
30°	— 1.5
40°	— 2.0
50°	— 0.5
60°	— 0.5
70°	+ 4
80°	+ 2
85°	—12

greater. Compensation is affected by the light reflected from the lower disk which passes through the upper disk and adds a sufficient amount to the brightness of the test surface. This construction is shown in section in Fig. 6. Table VI shows the re-

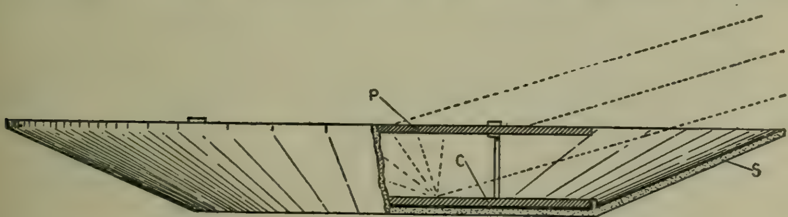


Fig. 6.—Half section of compensated reflecting test-plate. P. Test-plate of depolished white glass. C. Compensating diffuser of depolished white glass. S. Screen for cutting off light at 90°.

sults obtained with this form of construction. The angle of view of the photometer was normal to the plate. Here again the results of the compensation, while not quite so good as in the case of the reflecting plate, are, for practical purposes, about as good as could be desired. It should be noted, however, that the reflecting plate suffers under the disadvantage that in order to give these results, the angle of view must be normal to the plate. There does not seem to be any way of obviating this disadvantage. Also, the reflecting plate is considerably more cumbersome than the transmitting plate on account of its dimensions. Evidently,

the plate itself must be of sufficient size to cover the entire field of the photometer when the photometer is placed at the desired distance from it. The shading ring surrounding it must be large enough so that it does not begin to cast a shadow on the lower plate at too small an angle of incidence, for otherwise the compensation at high angles of incidence will be incomplete. In the construction investigated the test-plate had a diameter of 5 in. (12.7 cm.) and the entire apparatus a diameter of 10 in. (25.4 cm.).

The results of a number of the above tests are for convenience summarized in the curves of Fig. 7.

RESULTS OF ILLUMINATION TEST.

In order to form an idea of the magnitude of the errors which may be introduced into the results of illumination measurements

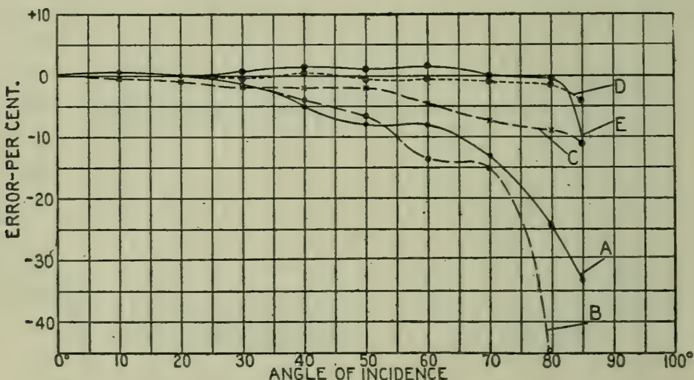


Fig. 7.—Errors of various test-plates viewed normally. A. Depolished transmitting plate. B. Polished transmitting plate. C. Depolished glass reflecting plate. D. Compensated transmitting plate. E. Compensated transmitting plate.

through test-plate deficiencies, an actual test of the illumination in a room at the Electrical Testing Laboratories was made. The results with a compensating test-plate were taken as standard and the others compared with them. The system of illumination was semi-indirect and may be taken as fairly typical of good modern practise.

The results as given in Table VII show a deficiency of 5.5 per cent. in the values yielded by the uncompensated transmitting test-plate and of 13.5 per cent. in the values of the reflecting test-

plate, which was viewed normally. The value 13.5 for the error of the reflecting test-plate is much larger than would be expected from the test results of such plates given above. The discrepancy may properly be ascribed to the light cut off from the plate by the photometer and the operator. However, this source of error is rarely, if ever, absent in using reflecting test-plates in interiors where the light is well diffused, and constitutes a serious disadvantage of the reflecting test-plate as compared with the transmitting type.

TABLE VII.—COMPARISON OF TEST-PLATES IN MEASURING ILLUMINATION IN A ROOM.

Test station	Compensated transmitting Foot-candles	Uncompensated transmitting		Uncompensated reflecting test-plate viewed normally*	
		Foot-candles	Per cent. of compensated	Foot-candles	Per cent. of compensated
1	12.1	11.7	97	10.9	90
Check after test	12.2	11.7	96	11.0	91
2	9.1	9.05	99	8.15	89
3	5.05	4.69	93	4.03	80
4	2.61	2.53	97	2.25	86
5	6.35	5.85	92	5.5	87
6	4.50	4.04	90	3.69	82
7	2.64	2.57	97	2.18	83
8	9.35	9.1	98	8.6	92
9	4.68	4.90	95	4.24	86
10	2.68	2.48	93	2.38	89
11	12.9	12.5	97	12.1	94
12	8.95	8.55	95	8.05	90
13	4.90	4.45	91	4.27	88
14	2.71	2.58	95	2.26	83
15	5.95	5.65	95	5.4	91
16	4.33	4.02	93	3.58	83
17	2.59	2.34	90	2.11	82
18	9.8	9.15	94	8.25	84
19	4.83	4.70	97	4.16	86
20	2.76	2.55	93	2.15	78
21	12.9	12.8	99	11.8	92
Mean illumination ..	5.21	4.95		4.51	
Percentage of compensated..			94.4		85.5

* Errors due in part to shadow of observer and of photometer.

If the 5 per cent. error as shown by the uncompensated transmitting plate be taken as typical, it will be seen that in all prob-

ability test-plate errors have not been a very serious matter from a practical standpoint, but it must likewise be conceded that to eliminate them entirely is very desirable.

Application to the Integrating Sphere.—In the theory of the integrating sphere the assumption is made that the window, the brightness of which is observed, is a perfect diffuser. Experimental work is now in progress looking to the adaptation of the compensation idea to these plates with a view to attaining a higher accuracy in sphere work.

APPENDIX.

Brightness of Test-plates as Seen in the Photometer when Measuring an Illumination of One Lumen Per Square Foot.

	Cp. per sq. in.	Apparent lumens emitted per sq. ft.
Depolished, transmitting	0.00049	0.22
Polished, transmitting	0.00056	0.25
Thick white flashed opal	0.00048	0.22
Thin greenish, flashed opal	0.00123	0.56
Depolished glass, reflecting	0.0180	0.81

The above-given figures represent the results of test of one plate only of each kind and are to be taken only as approximately indicative of the performance of the various classes. In the measurement of feeble illumination particularly, the plates having a relatively large brightness permit photometric settings to be made more easily.

DISCUSSION.

Ward Harrison: One redeeming feature of the test-plate error is that if the photometer measures 3 foot-candles it can be confidently asserted that more than that is being obtained rather than less. Its worst characteristic is that it usually tends to magnify variations in intensity of illumination. For example, in a photometric survey, the measurements taken near the side walls of a room will indicate a much lower intensity than in the central portion. The illumination is generally somewhat lower anyway, but since most of the light falls obliquely on the test plane at these stations, the test-plate error becomes a considerable factor and the photometer reading is still further reduced. The illumination on a desk in this portion of an office is often much more satisfactory than would be indicated by a foot-candle reading.

Again, in the case of industrial plants the fact has just been emphasized that illumination measurements should be made with at least one lamp shaded. A man working at his machine will often shade his work from the lamp placed directly above him, or nearly so, and if the residue of the illumination is measured, one may be unnecessarily startled at the low values obtained. It is simply another case of oblique lighting and the actual intensity may be easily 20 per cent. greater than the quantity measured.

Perhaps the most glaring of all cases of this error is that encountered when one attempts to measure horizontal illumination in a street lighting installation. Five and one-half per cent. has been given as the average error due to the use of an ordinary test-plate as determined in an illumination survey of a room equipped with a semi-indirect system. We have made several investigations where the error of the old type of plate appeared to be considerably greater than this. The magnitude of the error depends of course upon the character of distribution from the light sources; units which emit most of their light at angles near the vertical will give rise to a much less error in an illumination test than will units having a wide distribution of light. In the case of a semi-indirect installation the portion of the light which is reflected from the ceiling has a circular or concentrated distribution and the same is also often true of the portion of the light which is supplied by the bowl itself. With a system of direct lighting units having an extensive distribution, it has been found that the error in mean intensity runs as high as 10 or 12 per cent.

In conclusion I wish to express my appreciation of the work of Dr. Sharp and Mr. Little in producing this new test-plate. It will certainly afford a great degree of mental satisfaction to all who have occasion to make illumination surveys; from a practical standpoint the satisfaction is much increased by the fact that the test-plate has a polished surface. It is therefore not so liable to the very common error due to dust which is especially serious where an instrument is calibrated in one place and at a later date operated in another.

G. H. Stickney: This paper apparently confirms the distrust which I have held for many tests made with the reflecting type of test-plate. I have never used such test-plates to any extent, but

I have noted the very optimistic use of them by others. However, it must be recognized that such test-plates are exceedingly valuable for certain classes of measurements and when properly used give very useful results.

At the Boston Convention in 1907 (see Transactions 1907, pages 559, 562 and 571) some mention was made of an illumination photometer developed under the direction of Mr. W. D'A. Ryan, with which I had something to do. As Dr. Sharp says, this photometer was not particularly suitable for very low intensity measurements. It, however, met quite well the requirements in the class of problems which we were then meeting. It was never claimed for this photometer that it was suitable for all sorts of illumination measurements. It had the advantage over all other existing photometers in giving the proper value of light falling at all angles. In view of the fact that the discrepancy was then realized, it is somewhat surprising that up to the present no device has been in common use to effect a similar correction.

The arrangement described in the present paper seems to me to be an exceedingly important one, which should be applied as far as possible in all measurements taken in interiors where there is a large component of side light, either from reflecting walls or otherwise. The new device seems to embody some of the same fundamental principles of Mr. Ryan's photometer, although the method of mixing the light is of course quite different.

I believe we frequently encounter serious error in illumination measurements in undervaluating the diagonal light which often is most valuable in securing good illumination. For example, in this room at the present time, with the daylight coming in at the side windows, an ordinary photometer plate would not properly measure the light on the chairman's table, although it would more correctly measure the artificial illumination. I do not think this would be a happy instance to illustrate the excellence of the measuring qualities of an ordinary plate as commonly used in illumination photometers.

Mr. P. S. Millar: There have been two conditions surrounding the use of erroneous test-plates which have tended to reduce the ill effects of such errors. First, most surfaces which have been viewed in practise depart from the cosine law in the same di-

rection as do inaccurate test-plates. Second, the error has been more or less a systematic one applying in a general way to all photometric results and therefore less misleading than it might have been if applied to comparative results.

In spite of these conditions users of portable photometers have been uneasy regarding the test-plate error which has affected much of their work. It is accordingly very gratifying to know that we are in a fair way to eliminate such errors and I want to express my appreciation of the work of Dr. Sharp and Mr. Little in making available a practical device with which this last remaining systematic error can be removed from illuminating photometers.

Dr. C. H. Sharp (In reply): One speaker quite properly called attention to the fact that the reflecting test-plate, when properly used, apparently is inherently less in error than the transmitting plate. I believe, however, that because it can be viewed at pretty much any angle and is liable to be so placed that the body of the observer or instrument will cut off some of the light which it ought to get, it has disadvantages as compared with the test-plate rigidly attached to the photometer, which in practise renders it less reliable. I think Mr. Stickney has answered very well the question of the value of the light at 80 degrees. Very often it is not very important, and then again it may be very important, and when it is important, we surely want to be able to measure it. As to the area of the field in the apparatus illustrated, the diameter of the field is only about half the diameter of the transmitting test-plate. In a reflecting test-plate, the area of the field depends upon the distance of the photometer away. There has, however, been no practical difficulty due to an irregular field caused by an irregular distribution of the compensating light; the field is regular to a satisfactory degree. I perhaps should have said more in presenting the paper regarding Mr. Ryan's instrument. Ryan's compensated test-plate, for that is what it was, was a very ingenious thing. It was an endeavor to meet a difficulty which, even at that relatively early day, was well recognized, and it is probably a misfortune that it was not followed up.

PRESENT PRACTISE IN THE LIGHTING OF ARMORIES AND GYMNASIUMS WITH TUNGSTEN FILAMENT LAMPS.*

BY A. L. POWELL AND A. B. ODAY.

Synopsis: The general requirements for lighting are here discussed from a practical viewpoint. Typical installations are pictured and briefly described; and data covering a considerable number of buildings are presented in tabular form, giving dimensions, spacing, hanging height and size of lamps, type of reflector, equipment, etc. From this data average values of power consumption per unit of area (watts per square foot) are obtained.

INTRODUCTION.

A careful search through the TRANSACTIONS of the society and of technical literature reveals but little data on this field of lighting. It is true that the lighting of these buildings is a relatively simple proposition, yet the engineer who is about to design a new system usually desires to have available data with which to check his calculations. The authors of the paper were in a position to examine a considerable number of typical installations and correlate the material. They make no pretense of originality of design as the lighting of but comparatively few of the buildings inspected was planned by them.

The method of procedure in preparing the paper was to visit representative armories and gymnasiums located within a convenient radius of New York City, and note the facts as enumerated in the text; and, next, from observation and experience, to outline the principles involved in the lighting, as far as possible include these with the data.

Illumination tests were conducted in only a few instances as the time and expense, which would have been involved, would not have been warranted, for the illuminating efficiency of standard equipments is now fairly well known or can be estimated quite closely from similar cases. For checking calculations, the watts per square foot of floor area, with the proper modifications

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

deduced from experience, proves very useful. In each case the actual watts per square foot are given, but since the efficiency of the lamps found in service varies from 0.6 to 1.05 watts per horizontal candlepower, a table headed "Comparative watts per square foot" based on 1 watt per candle or approximately 10 lumens per watt is also included.

ARMORIES.

When one thinks of an armory, the drill shed alone is usually pictured; yet some of these structures are very elaborate indeed, having also a gymnasium, theatre, rifle ranges, bowling alleys, billiard room and the like. The subject therefore may be subdivided as given below.

Drill Shed.—This is, of course, the most important part of the armory and should receive the most attention. As a general proposition the usual form is a large open space with an arched roof. The size of those investigated varied from 600 ft. x 300 ft. (182.88 x 91.44 m.) (180,000 sq. ft.) x 100 ft. (30.48 m.) high, to 76 x 92 (23.16 x 28.04 m.) (7,000 sq. ft.) (11.58 m.) 38 ft. high. The roof is often partly glass to admit daylight and usually the iron work is exposed.

Many drill sheds have balconies for the seating of spectators, necessitating special lighting below to prevent dense shadows which would result if only the general lighting was provided. The floor varies considerably depending on the branch of service, cavalry having a very dark brown tanbark; infantry, light hard wood. Naturally the character of the floor has a marked effect on the quantity of light which must be supplied.

On account of the simplicity of operation and maintenance, the high efficiency of light production, the pleasing color of light, the steadiness and adaptability to reflectors giving any desired distribution of light, the gas-filled, tungsten filament lamp has become practically the standard illuminant for lighting drill sheds in the territory investigated. The large areas permit the use of high candlepower units and the lofty ceilings give hanging heights such that lamps are always well out of the ordinary angle of vision, overcoming any objection which might be raised on the question of intrinsic brightness. The wide range of sizes available make it possible to select a unit fitting any chosen spacing

giving the desired watts per square foot or foot-candles. Inexpensive fixtures, holders, sockets and reflecting devices are all standardized, thus avoiding the added cost of special designs which are sometimes attendant on propositions of these magnitudes.

The uses to which the drill hall is put are somewhat varied. The drilling of raw recruits takes place on only a portion of the floor and does not require the entire area to be lighted; battalion and regimental drills and reviews necessitate full illumination for ease of manoeuvres and inspection; gun drills in the coast defense and artillery sometimes need all lights out; or the armory is often rented to charitable organizations and the like for fairs and bazaars, which demand brilliant lighting as well as special decorative or spectacular effects. In any event sufficient light must be provided in all parts of the room to meet the most exacting conditions.

Type of Unit.—Appearance is one of the factors which must be given consideration, as the general effect of the room must be attractive, particularly if used for other than regimental purposes. Efficiency must also be considered as there are large areas to be illuminated and an extravagant fixture would make the cost of proper lighting prohibitive.

Eye protection must be assured as glare in such work as gun training would materially reduce the effectiveness of the unit.

Since the ceilings are usually broken by trusses and often quite dark, as a general proposition direct lighting is essential.

In most cases it is advisable to use either a translucent reflector or a unit which permits some of the light to escape above the horizontal, for if the ceiling is totally dark ones attention is involuntarily attracted and the room seems unpleasant. Occasionally, however, the floor is light enough to reflect sufficient light back to the ceiling even if opaque bowl reflectors are employed.

The type of distribution will vary with conditions. If the side walls are quite dark a unit giving a wide curve is inadvisable as far too much flux will be wasted by wall absorption. With light walls, however, the diffuse reflection will assist in the general illumination and concentration of the light is not as necessary.

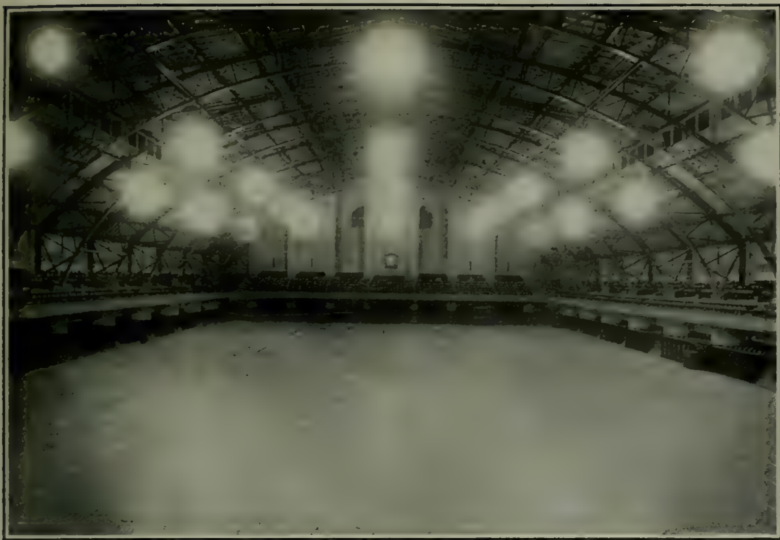


Fig. 1.—Night photograph 7th Regiment Armory N. G. N. Y., lighted by 1,000-watt gas-filled tungsten lamps in two-piece prismatic enclosing globes; average illumination 3.3 feet candles.

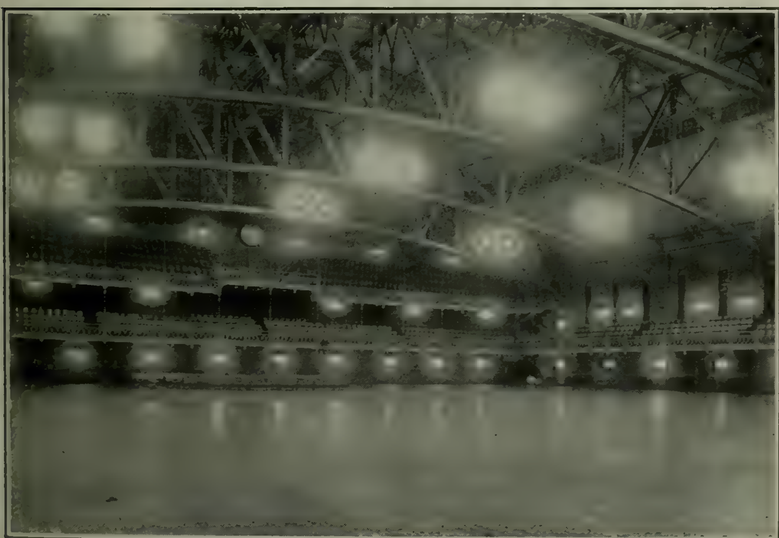


Fig. 2.—Night photograph 71st Regiment Armory N. G. N. Y., lighted by 500-watt gas-filled tungsten lamps in bowl prismatic reflectors.

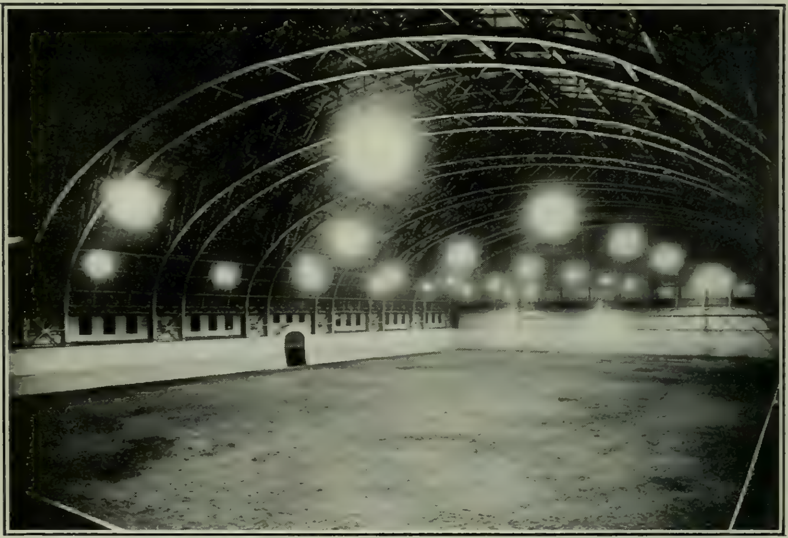


Fig. 3.—Night photograph Troop C Armory N. G. N. Y., lighted by 750-watt gas-filled tungsten lamps in deep bowl dense opal reflectors, average illumination 3.24 foot-candles.

Fig. 4.—Night photograph 22nd Regiment Armory N. G. N. Y., lighted by 1000-watt gas-filled tungsten lamps with deep bowl enameled steel reflectors.

Ease of Cleaning and Renewals.—On account of the high hangings employed, some sort of a lowering device should be provided. Most of the single unit fixtures weigh so little that a simple steel cable will safely support them; a cut-out hanger with lowering rope or wire simplifies this phase of building maintenance. In some cases the cut-out is omitted and the cable passes through a pulley, then down the sides of the room, the current-carrying wires hanging in loops.

Convenience of Control.—Although often not considered, this is an important point; for instance, in the coast defense armories when practising with the guns it is often desirable to hurriedly turn off any group of lamps. In the Brooklyn armories remote control is employed. The man in charge of the entire floor has a board with pilot lights and switches. At each gun are a number of push buttons, so that when the squads are firing the officer in charge of the firing can at once signal for any group of lamps to be extinguished. The whole armory can be thrown in darkness in an extremely short time. With the system of lighting formerly employed it required twelve men for this work with the attendant delay.

Intensity of Illumination Desirable.—From general consideration the cavalry and field artillery armories would require less light than those of the other branches of service, as they are not likely to be used for social purposes. This is counteracted, however, by the fact that the tanbark or loam floor absorbs a great deal of light and makes the place appear abnormally dark.

Average Figures.—The actual average watts per square foot for 15 drill halls with wood floors was 0.39; comparative 0.58;[1] for the 6 armories with loam and tanbark, actual 0.34; comparative 0.52.

Rifle Range.—The satisfactory illumination of this part of the building is too large a subject to be treated with any degree of completeness in a paper of this nature. In fact the British Illuminating Engineering Society devoted their entire May meeting to this phase of the art. A very valuable paper, by Mr. A. P. Trotter, and interesting discussion is reported in their June TRANSACTIONS.[2]

[1] *i. e.* with lamps at 10 lumens per watt.

[2] See *Illuminating Engineer*, (London) June, 1915.

So many facts enter into the problem, such as glare, contrast, intensity, uniformity, surface brightness, type of sight employed and so on, that it seems advisable to avoid all attempts at outlining the proper practise. Those interested can study the above reference.

However as an indication of the American practise a description is given of two indoor ranges, the first rather elaborate and the second simple.

There are two rifle ranges at the 69th Regiment N. G. N. Y. Armory, each 120 yards (109.72 m.) in length: in brief, they consist of two tunnels approximately 10 ft. (3.04 m.) high and 14 ft. (4.26 m.) wide, walls of brick and the ceiling of concrete. General illumination is provided in the firing room by small lamps and diffusing glassware. Across the tunnel at both the 50 and 75-yard (45.72 and 68.58 m.) points are placed mirrored trough reflectors[12] pointing downward, with 16 25-watt clear lamps each. A short distance above and in front of the targets (which are 2 ft. x 3 ft. 0.60 x 0.91 m. in size) is placed a third mirrored trough[12] reflector giving an asymmetrical distribution. In this 25-watt lamps are placed on 8 in. (20.32 cm.) centers. Heavy crystal glass plates are set in the floor in front of each target and the direct light from the reflectors passes through these and serves to illuminate the telephones and enables the scorers in the butts to prepare fresh targets. The night view in Fig. 6 was taken at the 60-yard mark or approximately midway between the two sets of lights in the gallery.

Princeton University has a short range with four targets which are controlled from the shooting position by means of a continuous wire and hand wheel. Above each target position is located a 60-watt clear lamp in a 45° angle aluminum finish steel reflector[13] 12 in. (30.48 cm.) in front of and 18 in. (45.72 cm.) above. The average illumination on the targets is approximately 12 foot-candles and is quite even.

Offices, Board and Company Rooms.—These are in fact club rooms with uses similar to those of the residential living room. Decorative yet comfortable lighting should be provided; the intensity must be fairly high and illumination even, owing to the diversified requirements; for cards, reading or writing in any

part of the room, piano playing and singing. There seems to be a tendency to decorate the rooms with dark finishes which, of course, detract from the apparent brightness of the room. The furnishings of some of these rooms are very elaborate; for instance, over $8,000 was expended on the quarters shown in Fig. 9. Yet in many such cases but little attention has been paid to the lighting system and its decorative qualities have been neglected. The fixtures used are often quite commercial, whereas an excellent field is offered for special designs in etched and colored glassware and appropriate metal work. One can conceive how the artist could work into the glass decoration, the company letter, U. S. A. monogram, or the eagle in a similar manner to those emblem bowls designed for lodge rooms with the elk's head, square and compases, etc. Diffused semi-indirect lighting with appropriate fixtures seems to be one logical method of treating this part of the building.

A view of the quarters of Company K, 71st Regiment N. G. N. Y., 20 x 45 ft., lighted by 36 25-watt tungsten filament lamps in prismatic enclosing globes [14 and 15] on "shower" fixtures and three arm brackets, is shown in Fig. 8. This rather high wattage is necessitated by the finish of walls and ceiling.

Company Locker Rooms.—Utility of equipment is essential here with lamps located between rows of lockers and fitted with efficient reflectors. Somewhat higher illumination should be provided in the neighborhood of the mirrors to facilitate dressing.

Company Store Rooms.—The accoutrements and spare supplies are placed on racks or shelves and must be fairly well illuminated for inspection and ease of locating a given article. Efficient equipment, so placed that an even intensity will be produced over the shelves, should be used. The work bench, which is often located in this room, should have one or two well shaded localized lamps; for minor repairs and cleaning of arms and other apparatus are carried on here.

Offices.—The lighting requirements of the private office have already been discussed before the society, and the practise is fairly well established. The regimental officers' rooms present no especial problem.

Corridors.—A low intensity of light is sufficient here; in the

less frequented parts of the building there should be sufficient light to prevent stumbling; but the main corridors should have enough illumination to readily distinguish a passerby, and to avoid any danger of accident in the event of a crowded condition.

The band room, quartermasters' and armorers' departments offer no especial problems beyond that of the average interior.

Stables.—The stables for the cavalry horses are often located in the basement of the armories; comparatively little light is required and the lamps should be of low candlepower, so that they can be placed at fairly frequent intervals without excessive energy being consumed. The ceilings are usually low and if too wide spacing is used some of the stalls will be in deep shadow. A fairly satisfactory arrangement is that of Squadron A, New York City. There is an aisle approximately 15 ft. (4.57 m.) wide between rows and stalls. Two rows of 25-watt clear lamps are used in each aisle without reflectors close to the whitewashed ceiling, one in front of every second stall. This gives plenty of light for harnessing, cleaning and feeding the horses, and the passageway is well illuminated.

GYMNASIUMS.

As in the case of the armory, the subject must be divided into several sections the first of which is the

Main Exercising Floor.—This is usually rectangular in shape with a moderate height of ceiling. The arrangement most frequently used has the running track as a balcony 6 to 8 ft. wide around all four sides of the room. In the center of the main floor are the principal pieces of apparatus, horses, bucks, jumping standards and parallel bars, while the flying rings and horizontal bars hang from the main ceiling. These can usually be pushed aside or drawn up out of the way for basketball, indoor baseball and wrestling, matches or practise. Below the balcony are found the exercisers of the various types and racks for wands, dumb-bells and Indian clubs.

The center part of the space requires even illumination of a moderate intensity with lamps so located that the hanging apparatus will not cause dense shadows. Particular attention should be paid to the shielding of the eye from the lamp filament, for one is forced to look upward a great deal when playing basketball.

Fig. 5.—Night photograph U. S. Naval Academy, Annapolis, lighted by 1000-watt gas-filled tungsten lamps with enameled steel reflectors and diffusing globes.

Fig. 6.—Night photograph rifle range 69th Regiment N. G. N. Y.

Fig. 7.—Night photograph rifle range Princeton University.

Fig. 8.—Night photograph, Club Room Company K, 71st Regiment N. G. N. Y.

Fig. 9.—Night photograph main exercising room Princeton University gymnasium lighted by 250-watt bowl-frosted tungsten lamps in dome shaped enameled steel reflectors.

If possible a slightly higher intensity should be provided in the neighborhood of the basket to facilitate shooting.

The illumination on the apparatus attached to the side wall below the track need not be as high as in the open space, yet in many cases it is necessary to provide a few outlets here with small lamps properly shaded to prevent dense shadows.

The general discussion on choice of a unit given under armories applies here also.

It is a regretable fact that in over 50 per cent. of the gymnasiums examined an old type of equipment was employed. This consisted of a 3, 4, 6 or 12-lamp cluster body with a white glass or enameled steel flat reflector about 12 or 15 in. (30.48 or 38.1 cm.) in diameter; in most every instance these were placed close against the ceiling and surrounded by wire cages or guards. This device is unsightly, gives a poor distribution of light, is inefficient, as light from one lamp must pass through the adjacent bulbs, and finally the whole of the filament is exposed to the eye. It would require too much space to tabulate the detailed data on all of these installations so the average figures are alone presented.

TABLE I.—AVERAGE DATA ON GYMNASIUMS LIGHTED BY TUNGSTEN FILAMENT LAMPS IN CLUSTERS.

	High Schools Number examined, 19			Colleges Number examined, 6			Y. M. C. A. Number examined, 5		
	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.
Area in sq. ft.	640	8,200	3,560	800	7,600	3,340	1,650	5,600	3,100
Ceiling height	9	31	17	12	30	19	15	25	23
No. outlets	3	43	15	3	5	4	4	18	9
No. lamps	12	252	73	20	32	30	16	108	54
Total watts	300	5,800	1,635	500	3,000	1,200	960	2,700	1,880
Watts per sq. ft.:									
Actual	0.26	1.1	0.65	0.10*	1.00	0.63	0.48	0.85	0.62
Comparative	0.25	1.05	0.63	0.095	0.95	0.60	0.46	0.90	0.59

* It seems unfortunate that the minimum watts per sq. ft. was found in a university of first rank.

As examples of more modern practise the following table is given, classified as to the type of reflecting device employed. (See Appendix No. 2.)

Space is not available for photographs showing all the different types of equipment in use. Fig. 9 illustrates the use of the dome shaped steel reflector[16] in the Princeton University gymnasium. An illumination test conducted on this floor showed the following results. The lamps are spaced closer to the center than ordinarily, as it was desirable to have the basketball court of

a higher intensity than the sides of the room. The minimum reading on a 30-in. (76.2 cm.) horizontal plane in the court was 2.7 foot-candles, the maximum 3.25 with an average of 2.95. Readings close to the wall apparatus indicated an illumination of about 1 foot-candle on the horizontal plane.

Fig. 10 shows the Union College gymnasium as it appears by night; a rather large white enameled reflector with concentric corrugations to break up striations is used above the lamps and a medium density opal deep bowl hangs below, shielding the eye and diffusing the light. Detailed data is given in Appendix No. 2.

Two other installations of those described should have slight additional explanation. In the Columbia University's main gymnasium the ceiling above the basketball court is largely openwork for ventilation. There are fifteen sections, each of which is further divided into nine squares. The metal work of the center square in each section was removed and 250-watt lamps in deep mirrored glass reflectors[19] are set with the mouth flush with the ceiling. This directs a strong light downward and the lamps are not visible unless one looks directly upward.

Below the running track or balcony, the under side of which is 23 ft. (7.01 m.) from the floor, are placed 14 150-watt lamps in deep bowl medium density opal glass reflectors.[28] These provide good illumination on the side wall apparatus and at the same time give some light in the horizontal direction, overcoming the "dead" effect which would result if only the strongly directional light was employed.

In the Northwestern University gymnasium deep bowl mirrored reflectors[19] are also used for direct lighting, but to prevent the ceiling being dark these units are placed on sheet iron cases and two small mirrored reflectors[29] with 25-watt lamps are used at each outlet for indirect illumination. The sides of the casing are cut away and art glass inserts reveal the monograms of the university in color.

For the twenty-two buildings, the data regarding which are given in Appendix No. 2, the average watts per sq. ft. is actual 0.78, comparative 0.90.

Swimming Pool.—These rooms are usually rectangular in shape with white tile walls and ceiling, in fact from a lighting

Fig. 10.—Night photograph main floor Union College gymnasium lighted by 400-watt tungsten lamps with enameled steel reflectors and diffusing bowls.

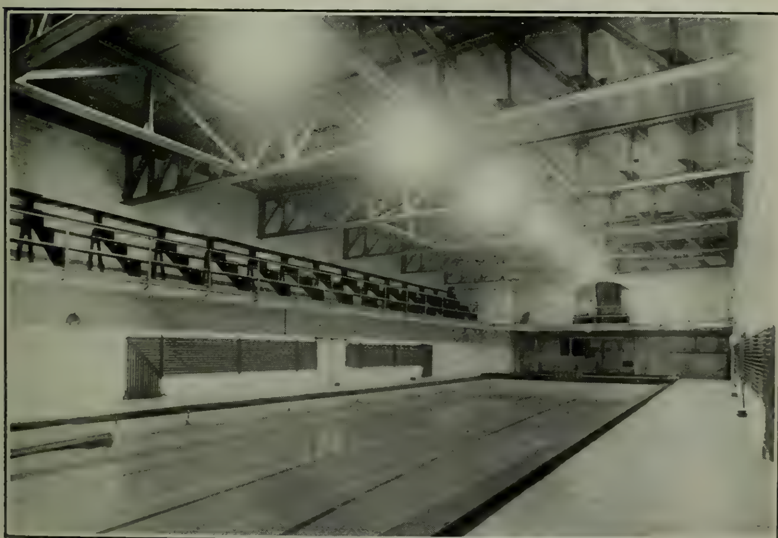


Fig. 11.—Night photograph swimming pool Princeton University, lighted by 250-watt bowl-frosted tungsten lamps and dome shapped enameled steel reflectors.

Fig. 12.—Night photograph swimming pool Union College, lighted by 150-watt bowl-frosted, tungsten lamps and bowl shaped light density opalescent glass reflectors.

Fig. 13.—Night photograph gymnasium locker room, lighted by 60-watt tungsten lamps and flared prismatic glass reflectors.

standpoint they are practically modified Ulbrich spheres. The type of reflecting device employed makes but very little difference in the illumination.

The following data were obtained from examination of eight pools with various reflecting devices; *viz.,* prismatic glass bowl, opalescent glass bowl, mirrored glass bowl, cluster body, flat white glass shade and enameled steel flat dome.

TABLE II.—ILLUMINATION DATA INDOOR SWIMMING POOL.

	Min.	Max.	Avg.
Area in sq. ft.	760	4,600	2,400
Ceiling height	9	24	13.5
Total watts	400	3,150	1,140
Watts per sq. ft.:			
Actual	0.31	0.70	0.47
Comparative	0.30	0.78	0.50

The swimming pool at Princeton University is approximately 35 x 130 ft. (9.14 x 39.62 m.) and is lighted by seven 250-watt bowl-frosted lamps in enameled steel dome-shaped reflectors[16] located in a row down the center of the room between girders. By means of a temporary bridge illumination readings were taken on the surface of the water, giving an average of 1.7 foot-candles. It is to be noted how clearly visible is the floor of the pool although containing from 4 to 10 ft. of water. (See Fig. 11.)

The pool at Union College, Schenectady, as it appears by night is pictured in Fig. 12; 150 watt bowl-frosted lamps are used in light density opalescent glass reflectors, bowl shaped 10 in. in diameter,[30] placed in three rows, on equal spacings. The dimensions are 45 x 100 ft. (13.71 x 30.48 m.) giving 0.70 watt per sq. ft. Here also the lanes marked on the bottom of the pool are clearly visible.

Shower Room.—These present no especial problem in regard to the lighting, but on account of the high percentage of vapor present in the air it is advisable that moisture-proof electric fittings be employed.

Locker Rooms.—Double rows of lockers, with aisles between in most cases, extend to the ceiling. The athletes dress in these aisles. Mirrors are ordinarily placed at the ends of rows on the main aisle. Low ceilings of light color make practical the use of low candlepower, all-frosted lamps without reflectors, with sock-

ets set flush. In a number of the installations examined 25-watt lamps are used on 8 ft. centers. Larger lamps with suitable reflectors localized near the mirrors on the main aisle are essential. A 60-watt lamp with bowl-shaped dense opal reflector between pairs of mirrors proves satisfactory.

The night view in Fig. 13 shows a locker room with single tier lockers in which general illumination is provided. The finish is dull gray throughout. Sixty-watt clear tungsten filament lamps in flared prismatic reflectors[22] are placed close to the 11 ft. 3.35 m.) ceiling on 8 x 14 ft. (2.43 x 4.26 m.) centers, giving one half watt per sq. ft.

Running Track.—In most cases this extends around the main exercising room, but the one at Columbia University is somewhat longer than the average and the major portion is in the form of a rather low tunnel 10 ft. high by 11 ft. wide. Glaring light sources would prove very objectionable here so 60-watt clear tungsten filament lamps are used in 12 in. opalescent glass semi-indirect dishes[31] on 28-ft. (8.53 m.) centers.

Wrestling, Boxing and Fencing Rooms.—The finish is frequently light and the ceiling smooth; the room is often decorated with prizes, pennants, etc., so the decorative element of the lighting becomes of more importance. The indirect systems are quite applicable.

A description of the fencing room at Columbia University will illustrate a typical case; the dimensions are 26 x 38 ft. with a 14 ft. white ceiling; two outlets are provided and 400 watt gas-filled tungsten filament lamps in leaded white glass semi-indirect dishes[32] 20 in. in diameter furnish very satisfactory illumination. The energy consumption is 0.8 watt per sq. ft. actual comparative 1.14.

Medical Director's Office.—This room has the ordinary requirements for office lighting, providing plenty of light in all parts of the room for physical examinations. Totally indirect lighting is employed in quite a number of the installations visited, averaging approximately one watt per square foot.

Squash Court.—These are usually rectangular in shape and approximately 15 x 30 ft. (4.57 x 9.14 m.) in size. Many have white ceilings which will permit the use of totally indirect or

semi-indirect lighting. Since the walls are finished in dark red, an imitation of mahogany, quite a high wattage will be required with either of the above systems. The Squash Club of New York is experimenting, at the present time, with semi-indirect bowls and gas filled tungsten filament lamps. The courts at the Yale Club are equipped with porcelain enameled totally indirect fixtures. It is quite important to avoid glare and reflections from the varnished surfaces.

Handball Court.—The board must be well lighted, and a rather high component of illumination on imaginary vertical planes covering the whole area of play should be provided, as it is necessary to see the ball in its travel. The angle type reflector meets these conditions excellently, completely shielding the eye, for the player is always looking forward. The courts at Columbia University are 24 x 21 ft. (7.31 x 6.40 m.) with a 13 ft. white ceiling. Two 250-watt lamps are placed on each court close to the ceiling in angle type porcelain enameled steel reflectors,[33] giving slightly over one watt per sq. ft. for the effective area.

In the Newark Y. M. C. A. the board is located below the running track and is especially lighted by 25 watt lamps in half hand metal shades on the under side of the track, spaced on 4-ft. centers. The general illumination of the room is adequate when one is playing back.

Trophy Room.—This is usually quite elaborate and decorative lighting systems are desirable. On account of the variety of decoration, it is inadvisable to present any average figures.

ACKNOWLEDGMENT.

The authors express their appreciation of the assistance in the compilation of the paper rendered by the members of the Department of Water Supply, Gas & Electricity of the City of New York, Mr. G. B. Nichols, chief engineer of the New York State Architect's Office and Messrs. G. H. Stickney, R. E. Harrington and E. F. Carrington of the Edison Lamp Works.

APPENDIX II.—Data on Gymnasium Lighting Classified as to Type of Equipment Used.

	Dimensions in feet	Area in square feet	Height of ceiling in feet	Color of walls	Color of ceiling	Number of lamps	Size of lamps in watts	Total watts	Watts per sq. ft.		Diam. of refl. in inches	Height of lamps in feet	Remarks
									Actual	Com-pr't've			
Enamel steel dome shape													
Princeton Univ.	100 x 165	16,750	40	Cream	Brown	32	250 b. f.	8,000	0.48	0.53	18 [16]	24	See text
Chicago Univ.	50 x 90	4,500	35	Green	Cream	10	500 cl. vacuum	5,000	1.1	1.22	20 [17]	20	
Newark, N. J., Turn Verein	50 x 70	3,500	20	White	White	8	250 b. f.	2,000	0.57	0.64	18 [16]	17	
Newark, N. J., National Turn Verein	37 x 75	2,800	40	Buff	Brown	12 4	150 cl. 100 cl	2,200	0.80	0.89	18 [18]	25	
East Side Y. M. C. A., New York City	37 x 64	2,400	24	Buff	White	2	500 b. f.	1,000	0.42	0.60	20 [17]	18	
Girls High School, Brooklyn	28 x 85	2,400	30	Cream	Cream	3	500 cl.	1,500	0.62	0.69	20 [17]	27	
Boys Trade School, Worcester, Mass.	48 x 85	4,100	19	Buff	White	15	150 cl.	2,250	0.55	0.61	18 [18]	18	
Mirrored bowl reflector													
Orange, N. J., High School	45 x 72	3,400	18	Yellow	White	15	60 cl.	900	0.47	0.47	8	Mouth flush with ceiling	
Holstein Park Gym., Chicago, Ill.	36 x 60	2,160	28	Brick	Dark	12	150 cl.	1,800	0.83	0.92	10½ [19]	20	
Columbia Univ., New York City	Semi circular 94' Radius	14,000	35	White	White	15 14	250 b. f. 150 b. f.	5,800	0.42	0.47	10½ [19]	*	*See text
Northwestern Univ., Chicago, Ill.	235 x 130	29,000	50	Brick	Light	157	100 cl.	15,700	1.00*	1.00	10½ [19]	18 to 45	*See text
Enamel steel deep bowl shape													
Columbia Univ., Auxiliary Gym.	Semi-circular 60' Radius	5,650	20	White	White	13	400 b. f.	5,200	0.94	1.35	12 [20]	18	
Flared opal glass reflector													
West Orange, N. J., High School	27 x 70	1,890	16	White	White	6	250 b. f.	1,500	0.80	0.89	12 [21]	15	
Flared prismatic reflector													
Y. M. C. A., Newark, N. J.	48 x 66	3,170	30	Buff	White	16	100 cl.	1,600	0.50	0.52	12 [22]	20	
Opalescent glass semi-indirect dish													
Polytechnic Inst., Brooklyn, N. Y.	53 x 82	4,350	16	White	White	8	400 cl.	3,200	0.73	0.96	16 [23]	14	
Opalescent enclosing globe													
Y. M. H. A., New York City	40 x 70	2,800	25	White	White	2	750 cl.	1,500	0.54	0.83	12 [24]	20	
Adelphi Academy, Brooklyn	50 x 40	2,000	17	Buff	Brown	4	300 cl.	1,200	0.60	0.80	12	12	
Pratt Inst., Brooklyn	53 x 78	4,100	35	Buff	Buff	17	500 cl.	8,500	2.05	2.90	12 [24]	24	
Enamel steel reflector and enclosing globe													
U. S. Naval Academy, Annapolis	100 x 220	22,000	70	Brick	D.wood	22	750 cl.	16,500	0.75	1.15	18 [11]	45	
Union College, Schenectady	60 x 120	7,200	40	White	Brown	18	400 cl.	7,200	1.00	1.10	39 [27]	24	See text
Bowl prismatic glass													
Y. M. C. A., Orange, N. J.	45 x 56	2,500	24	White	White	9	150 b. f.	1,350	0.54	0.60	10 [25]	18	
71st. Regt. Armory, N. Y. C.	30 x 75	2,250	24	Cream	White	50	25 b. f.	1,250	0.56	0.53	6 [26]	23	5 light fixtures

APPENDIX III.

1. Holophane Realite 06260 V. S.
2. Holophane prismatic reflector XE-500.
3. Holophane prismatic reflector XI-250.
4. Benjamin fixture 6158.
5. Holophane Sudan reflector 1224-16″.
6. Holophane prismatic reflector XE-100.
7. Benjamin fixture 6124.
8. G. E. Novalux form 1 157078.
9. Benjamin fixture 6179.
10. Benjamin fixture 6199.
11. Wheeler multiple Mazda fixture 2702.
12. Frink mirrored reflectors, marketed by the H. W. Johns-Manville Co.
13. Ivanhoe metal reflector AL-60.
14. Holophane pendant ball 3063.
15. Holophane Stalactite 3354.
16. Ivanhoe metal DED-250.
17. Benjamin flat cone 5503.
18. Ivanhoe metal DED-150.
19. National X-Ray Beehive 765.
20. Ivanhoe metal BEI-500.
21. Luna reflector 14, made by the H. Northwood Glass Co.
22. Holophane distributing reflector 6072.
23. Doric hemisphere 1234, marketed by the Lighting Studios Co.
24. Ivanhoe promotion fixture 758.
25. Holophane prismatic reflector XE-150.
26. Holophane glass reflector 2633.
27. Mazda Monolux diffuser unit 1329.
28. Holophane Sudan glass reflector 01225-10″.
29. National X-Ray reflector E-60.
30. Holophane Druid glass reflector 3024-10″.
31. Camia dish, marketed by the Opalux Co.
32. Mazda Monolux fixture 3320.
33. Ivanhoe metal REL-250.

DISCUSSION.

Mr. G. B. Nichols: Mr. Powell's paper on armory and gymnasium lighting appears to have come before this Society at a very opportune time, in that probably within the next year there will be a large number of armories started throughout the country, following up the movement of increasing the facilities of the armories, which has been advocated since the European War. This paper I believe to be very complete in obtaining the latest data on the armories throughout the East, in which the latest equipment has been installed. The paper will also be of considerable interest in designing the equipment for the new Eighth Regiment Coast Artillery, referred to in the paper as being the armory with 180,000 square feet of floor area in the drill shed, which is probably the largest armory that will be constructed in this country for a considerable period. The size of this armory can be conceived, when we say it is three and one half times the size of Madison Square Garden.

In the lighting of armories, as brought out in the paper, considerable attention should be paid to the character of the floor, for in armories designed for calvary use, generally some form of tan bark is installed and, on account of the absorbing qualities of this material, double the foot-candle intensity will be required to obtain the same lighting effect. Up to four years ago the majority of armories of New York State were lighted by incandescent and gas lamps and, in a few cases, by arc lights. At this time considerable study was carried on, particularly in New York City, to determine the advisability of installing flame arcs and a number of installations were made at that time. It is to be regretted that these installations, which have been in use such a short period, should now be supplanted with incandescent lamps of the gas-filled type.

One of the armories mentioned in the paper, namely, Troop C Armory in Brooklyn, which is one of the newer armories in New York, during the last four years has had three different types of lighting units installed in the riding ring. Originally there were 114 enclosed arc lamps. Three years ago this installation was changed to flaming arcs, 14 having a total wattage of approximately 18,000 watts being installed. In this installation the

average foot-candle intensity for the entire room was 3.6; the maximum was 5.5, and the minimum 1.2. The 1.2 readings, however, were at the very outer edge of the riding ring and are of slight importance. The watts per square foot figure was 0.093. The estimated cost of lighting for this armory for one year, including maintenance for this installation was $1,348.55.

A year ago this installation of flame arcs was removed and gas-filled, incandescent lamps were installed, which installation is the one mentioned in Mr. Powell's paper as having a total wattage of 22,500 watts. Photometric readings showed the following intensities: average 3.24, maximum 4, minimum 1.82. Watts per square foot 0.129. The estimated total cost of lighting, including maintenance per year and lamps replaced, is $1,235.23, being a slight decrease from that of the flame arc installation.

On comparing the two systems, the slight difference in annual cost is very little importance, the main feature being to decide the relative merits of the two installations. The consensus of opinion was that the gas-filled lamps are preferable to flame arcs for the following reasons:

1. Colors are not distorted to such an extent under the gas-filled lamps. This is particularly objectionable where the armories are used for dress occasions, where there is considerable objection to having the colors of the uniforms very much distorted.

To add to the information given in the schedule, I would state that photometric tests have been made on the following armories:

Troop C, 3.24 foot-candles; 10th Regiment Armory, Albany, 2.32 foot-candles; 47th Regiment, small shed, 1.46 foot-candles. It appears that the 47th Regiment lighting should be increased, as this installation was not designed for the equipment now installed.

I would also call to your attention the State Armory at Albany, mentioned in the paper, which is typical of what might be done in an armory already lighted by incandescent lamps. At this armory, two gas-filled lamps were installed in place of a lighting fixture containing eight 250-watt tungsten lamps. The old fixtures were simply taken down and new ones installed in their place, with two lamps at each outlet, the fixtures simply being

suspended by wire cables from the overhead trusses, making a very inexpensive outfit. This change could be made at almost any armory at a slight extra expense, which would probably be saved during the first year.

Considerable improvement I believe is possible in the method of trimming. At the present time the most practical way seems to be to trim by extension ladders, which is done with considerable difficulty, the lamps being generally about 35 feet from the floor. As yet no successful lowering device of moderate cost has been developed.

In reference to gymnasium lighting, I would state that in my judgment the values given in the paper are the minimum rather than the average for good lighting. In discussing this form of lighting with gymnasium instructors, it appears to be the consensus of opinion that the illumination should be very high and well distributed, on account of the vast work being carried on. In some gymnasiums the foot-candle intensities run as high as 6, which is not excessive.

Would it not be possible to reach the lighting equipment in an armory from a walk-way constructed in the trusses in the roof and thus eliminate the necessity of lowering the lamps? It would seem that the girder construction and wide spacing of a few large units would make this not only possible, but probably most advisable. I believe the Colesium in Chicago has such an arrangement, with a main walk-way lengthwise of the building, protected by a pipe hand-rail on either side and branch walkways crosswise the building.

MR. L. C. PORTER: Reference has been made in this paper to the lighting of rifle ranges. This is a subject which warrants a great deal more study than has been given to it. The ultimate aim of this indoor practise is to teach a man to shoot out-of-doors, to handle a rifle, to load, to pull the trigger, to properly sight, etc. In most rifle ranges the conditions are vastly different from what they are out-of-doors. It is very common to have the target highly lighted and the space between the targets and the shooter entirely dark; sometimes there is enough light to enable the shooter to load the gun. Experiments which have been undertaken seem to indicate that it may be better practise to have

some illumination between the man and the target, thus at least approximating a little more closely outdoor conditions.

One method that has been successfully tried to accomplish this is by the use of flood lighting, by projecting a beam of light from behind the shooter onto the target. There will be enough stray light to give some illumination the entire length of the gallery. Of course, in this case care must be taken that the target does not reflect the light specularly back to the shooter.

Mention has been made of the Yale gymnasium; being a Yale man myself I have done some work in that gymnasium and I think that one word of caution should be given to those who are working on gymnasium lighting. It seems to me that it is necessary to have light of high intensity in gymnasiums, especially in ring work and bar work. However, it is of extreme importance to have it well diffused; under no circumstances should a glaring light source be used. There are many times when a man is facing the ceiling and the light source, and in tumbling and ring work, as has been mentioned, it is necessary for him to see very quickly, to catch the flying ring. In such cases glaring light sources may result in serious accidents.

Mr. R. B. Ely: I should like to ask Mr. Powell as to his experience with lamps used over swimming pools, whether he ever uses enclosing globes. I think enclosing globes would take care of and eliminate the danger of exploding and broken lamps. The broken glass may be the cause of accidents.

I know of a case where a man brought suit for having one of his patrons cut by a piece of glass in the bottom of the swimming pool, and another instance where a young man started to fool with a lamp and accidentally touched the base and was killed.

Mr. A. L. Powell: One of the gentlemen, who has discussed the paper, mentioned that the intensity of illumination in the 23rd Regiment Armory, Brooklyn, was somewhat low. An examination of the data presented shows this to be undoubtedly true, for there is but 0.25 watt per sq. ft., whereas the average value is approximately 0.5 watt per sq. ft. using the gas-filled tungsten lamps. This average value, we believe, will give satisfactory results under ordinary conditions.

It was suggested that a platform or run-way be built among the

roof trusses, from lamp to lamp, instead of providing lowering devices. One speaker pointed out the greatly increased investment necessary to build a platform strong enough, and the safety factor must also be very carefully considered, for in most instances the iron work is from 50 to 100 ft. above the ground.

Floodlighting may be of use for those rifle ranges with no obstructions, but in some galleries the construction is such that this type of lighting would be impracticable. These particular cases are arranged so that but one target can be seen from the gun position. This is done by placing partitions or shields at points along the gallery, with apertures in the line of the target acting in the same manner as the light screens on a standard photometer bar. One has to be directly in line with these series of holes in order to see the target, else all that is visible is the black shield (see Fig. 6.) A projector unit would not serve in this case unless there were one for each target.

Other speakers called attention to the fact that data were presented on a number of gymnasiums which were far from very well illuminated, as indicated in the minimum values given. This is indeed too true, particularly in reference to those exercising rooms listed in Table 1, and as is stated in the paragraph above this table, it is to be hoped that these conditions will be remedied. There is a large field open for improvement in this class of lighting. It can be seen that quite a number of gymnasiums were visited and those described under Appendix 2 represent the best conditions met as far as proper equipment and suitable intensity of light are concerned. Even in this table there are but few examples of what might be termed the best lighting.

The authors' attention has never been called to the danger of broken glass from the lamps about swimming pools and in locker and wash rooms. In none of the gymnasiums visited was there any special provision made to protect the lamp from water and to prevent glass falling to the floor. It does not seem that there should be any more appreciable danger in walking about these rooms in one's bare feet than in walking about the bath room in the home which is ordinarily lighted by a standard type of fixture and incandescent lamp.

Mr. G. B. Nichols: In reference to the breakage of lamps

and globes in swimming pools, this breakage has not been of any great importance, unless in swimming pools where games are carried on, which are likely to break the globes. In these instances, it seems preferable to install some form of wire cage over the fixture. I believe, however, that these conditions can be met to a considerable extent by using some form of metal reflector; the breakage of the lamps is not a serious matter.

PRACTICAL HINTS ON THE USE OF PORTABLE PHOTOMETERS.*

BY W. F. LITTLE.

Synopsis: This paper outlines a desirable procedure in the conduct of photometric tests with portable apparatus. It discusses the planning of a survey; a description of the condition of the installation and precautions which should be taken to make the results useful; a method of testing candlepower, illumination intensity and brightness; good practise in the maintenance of photometric apparatus; photometric errors inhering in photometers and accessories, together with means of avoiding them; photometric accuracy and test results.

In the use of portable photometers the same photometric principles prevail as in the operation of stationary or laboratory types of photometers; indeed, a portable photometer is no more than a stationary photometer reduced in size and with a test-plate substituted for one of the photometric surfaces. The only principle peculiar to the use of portable photometers is, therefore, that of the cosine law as applied to the test-plate.

The practise of photometry as applied to portable photometers differs radically from that followed with stationary photometers, in that the conditions of use are not standardized, the purpose and the method of test are usually not so definitely indicated, and the practitioner is often less experienced. Also, the auxiliary instruments used in connection with portable photometers are frequently less accurate than those used with stationary photometers.

These differences, in combination, contribute to surround the use of portable photometers with a liability to error which is greater than that experienced in the use of stationary photometers. The successful use of portable photometers demands more exercise of good judgment, and a more general knowledge of photometric principles and practise than is usually required of the photometrist in routine laboratory work. In view of these facts it has been thought desirable to present the results of the writer's

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

experience in the use of portable photometers, making it available to others who may engage in this class of testing.

AN ILLUMINATION SURVEY.

In the conduct of an illumination test the first fundamentally important consideration is to arrive at a correct understanding of the purpose of the lighting installation and of the purpose of the test. It is then important to determine whether the installation tested is representative and whether the samples or sample, if only a portion of the installation is tested, are typical of the whole. The test should be so planned and described that there shall be a minimum of danger that any incorrect conclusions will be drawn. These statements, though generalities, may be applied in specific cases and when applied will contribute to the usefulness of the data obtained through illumination tests.

DESCRIPTION OF INSTALLATION AND CONDITIONS.

The photometrist's note-book should contain a full description of the important features of the installation including the condition of pressure or voltage and consumption, the condition of illuminants and other accessories with special references to their suitability for the service, their cleanliness and age; variables affecting the test as, for example, pressure fluctuations with artificial illuminants, change in sky brightness in daylight tests, etc.; description of the environment including dimensions, finish and location of light sources in indoor, and corresponding descriptions in outdoor tests. The refinement to which this description is carried must, of course, depend upon the nature and purpose of the survey. When the measurments are of illumination intensity or brightness, the description should include a statement of the total flux and of the distribution characteristic of the light source.

The description should give very specifically the location of the installation under test so that it may be readily identified and conditions duplicated at any time. It should have in view the purpose of affording a basis for intelligent discussion of results after the tests are complete.

OPERATING DATA.

It is important to measure the pressure and consumption values

of the illuminants. From such data deviations from standard initial operating conditions can be allowed for.

TESTS OF CANDLEPOWER.

Location of Photometer.—It is to be presumed that in measurements of candlepower a certain angle or series of angles in a vertical plane is stipulated for investigation. It is important to know whether or not the source tested has symmetrical distribution at such angles. If not, care should be taken to select a direction in which the intensity is the mean for the angle investigated. If this is not feasible the tests should be made in a number of directions. It is good practise where a second photometer is available to make simultaneous tests on opposite sides of the illuminant.

Stray Light.—An important step which should be taken in preparing for measurements of candlepower is the proper screening of the photometer against stray light. A portable photometer is likely to be used in the measurements of candlepower elsewhere than in a well equipped laboratory where all proper arrangements are provided. The conditions for the test are likely to be improvised and the need for proper precaution against stray light is, therefore, the greater. It is important to look from or through the photometer toward the light source and make certain that no other light source illuminates the test-plate, and that no surface reflects an appreciable amount of light upon it. A simple procedure is to introduce a suitable lens between the photometer device and the light source which will enlarge the field of view permitting the easy examination of the entire field. Most portable photometers are equipped with one or more screens near the test-plate which limit the area to which the test-plate is exposed. Frequently, however, additional screens are necessary to cut off all stray light.

Alignment of Photometer.—The tubes carrying the test-plate of the photometer, and the screens, limit the light falling on the test-plate, so that the photometer can be aimed directly at the lamp. If the test-plate employed is placed across the angle of the tube so that the rays fall upon it at 45°, the position of the test-plate is particularly important. Unless suitable facilities are provided, much time may be consumed in properly aligning a

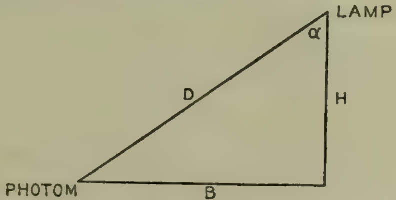
photometer in candlepower measurements. A method which experience has shown to be convenient consists in the use of the elbow tube of the photometer with a simple telescope and cross hairs described elsewhere. With a protractor and plumb bob attached to such a telescope a ready means of determining the height of the lamps is at hand, also its distance from the photometer may be determined. The protractor also affords a quick and accurate measurement of the angle between the vertical and the direction of light, without the necessity of accurately leveling the photometer.

Test-plate.—Both reflecting and transmitting test-plates are used in candlepower measurements. As the subject of test-plates is to be discussed before this convention in another paper[1] the discussion in this connection will be limited. The test-plate set at 45° to the rays of light suffers under the disadvantages of requiring more accurate alignment, but has the advantage of being more easily screened and of rendering a brighter field.

Calculations.—In the conduct of candlepower tests it is of course necessary to know the angle of measurement and the distance between the lamp and the photometer.

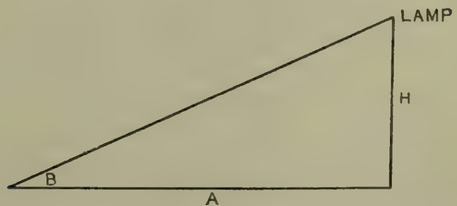
Computations may be based upon the following:

$$\left.\begin{aligned} \text{C.P.} &= \text{F.C.} \times d^2 \\ d^2 &= h^2 + b^2 \\ d^2 &= \left(\frac{b}{\sin \alpha}\right)^2 \end{aligned}\right\} \text{Fig. 1.}$$



To determine *h* where the height cannot be measured directly, a base may be laid off and from the angle determined, *h* can be computed.

$$h = a \text{ Tan. } \beta \quad \text{Fig. 2.}$$



The photometer may be located so as to measure any angle by

[1] Sharp, C. H., and Little, W. F., A compensated illumination test-plate.

first determining the height and then laying off the proper base.

$$b = \frac{\text{Tan. } a}{h}$$

In all computations it is to be remembered that the distances are measured vertically, and horizontally, and they are determined with respect to the test-plate and not the floor or street level.

Means of determining street grades and exact location of lamps are discussed later.

The signs and tangents are used in the above formula as they may be read directly from a slide rule.

ILLUMINATION MEASUREMENTS.

It is obvious that illumination measurements should be made in a plane, the illumination of which is the principal purpose of the installation. This refers to height of horizontal plane or to inclination of other planes which may be studied. In some cases it may be desirable to determine the flux density of the light incident on a surface inclined to the horizontal. As in the case of the study of the illumination of school desks, show windows, machinery, etc.

During the test it is very essential to record service conditions simultaneous with the photometer readings; for example, the voltage should be noted for each reading or the averaging voltage for a series of readings. With the data and the characteristic curves of the illuminants the measurements may be corrected to the standard condition (Fig. 3).

Selection of Test Stations.—Practise in the selection of test stations falls into two general classes: in the one the purpose is to determine the total flux of light on a given plane and to employ this value to determine the illumination efficiency of the installation. In the other the purpose is to determine the flux density at important points without the intention of making a compete study of the installation. Each practise has its own field of usefulness.

If irregular or special locations for test stations are selected it is usually impracticable to arrive at a figure for the illumination efficiency.

In the writer's work it has usually been desirable to make the more complete study of an installation from which the efficiency may be determined, and the practise has been to select syste-

matically arranged test stations, and to supplement them by such measurements as may be desired, at points of special significance. In such practise it is customary to divide the floor space beneath the illuminants into equal areas, the illuminants being over the intersection of boundary lines of such areas rather than over the centers of the areas. Fig. 4 illustrates such a layout for a bay illuminated by four lamps). The numerical average of the horizontal illumination intensities for test stations so disposed will be the mean flux density for the entire plane if a sufficient number of test stations are selected. For the construction of illumination

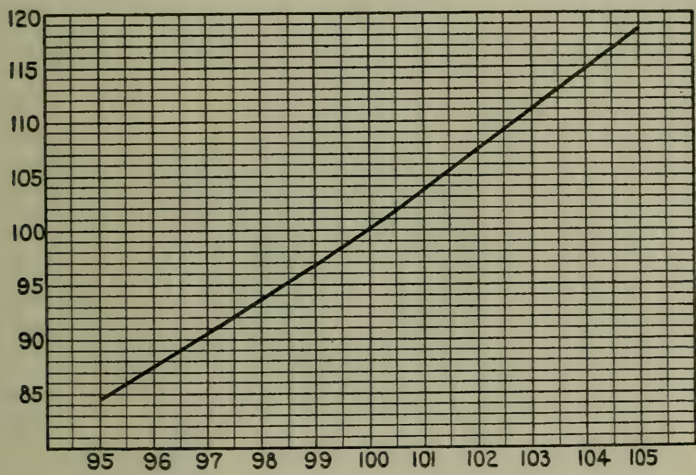


Fig. 3.

curves, and for further information regarding the uniformity of the lighting, it is usually desirable to supplement these regularly spaced test stations by other measurements made perhaps directly beneath lamps, at points where a minimum intensity is anticipated, and at other points of special interest. Measurements directly beneath the lamps also afford some indication as to the rating and the uniformity of the lamps.

Photometer Test-Plate.—As has been indicated the test-plate is the one elemental feature which differentiates the portable photometer from the stationary photometer, or the illumination photometer from the candlepower photometer. It is also the one feature of a photometer in which a known systematic error has existed. The reference is to the departure of the brightness char-

acteristic of the test-plate from Lambert's cosine law. This error has been tolerated because no simple and adequate means of avoiding it have been available. In the compensated test-plate described in another paper[1] this error is eliminated.

The error of the transmitting test-plate differs from that of the reflecting test-plate in that for a given angle it is constant for all directions of incident light because the surface is always viewed normally. The error of the reflecting test-plate likewise varies with the angle, and for any given angle may vary with the azimuth or the direction of light. In the cases where the reflecting test-plate is viewed normally one of these variables is eliminated.

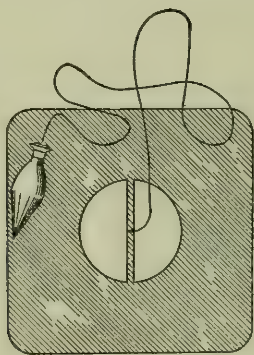


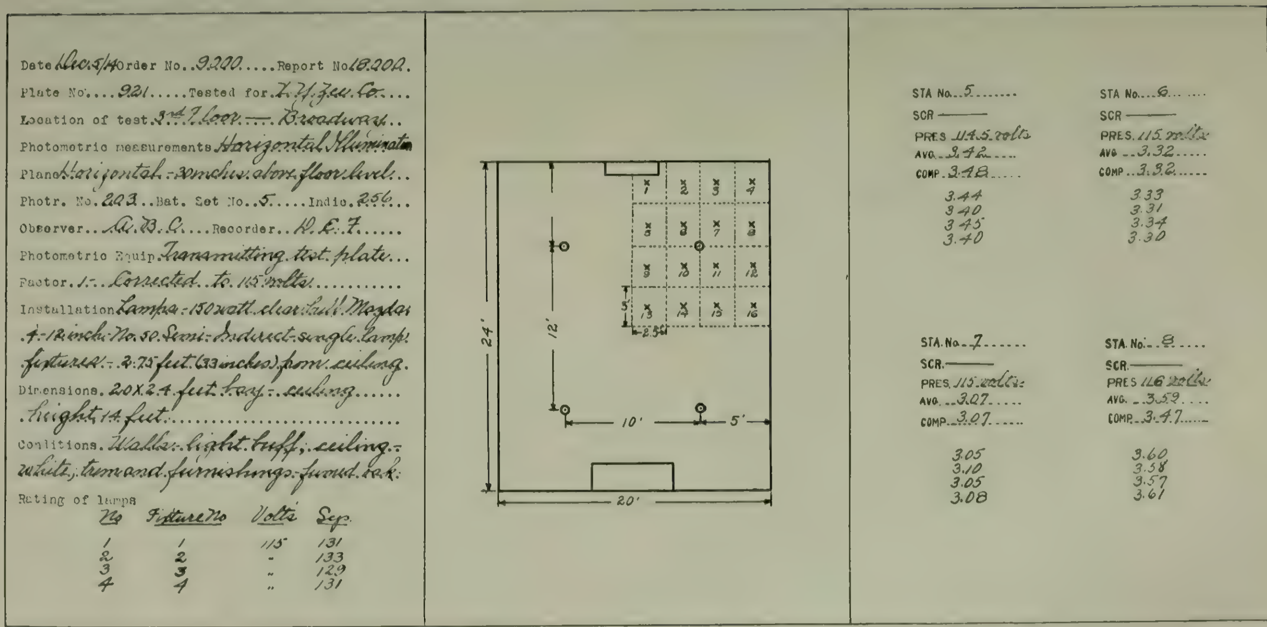
Fig. 6.—Plumb-bob suspended from center of an opaque ring.

With the transmitting test-plate the photometer and the observer may be located below the plane of illumination and may, therefore, avoid shadows upon the plane. When a reflecting test-plate is employed it usually is difficult to avoid casting shadows upon the plate. The obvious procedure is to choose the direction of view which will minimize the obstruction of light on the plate, by the photometer and observer, having due regard to the selection of the angle of view which will avoid large errors due to the departure from cosine law.

The reflecting test-plate may be used to good advantage in inaccessible places, such as show cases, walls, ceilings, shelves, packing cases, letter files, etc.

In the extended study of illumination on a given plane it is

[1] TRANS. I. E. S., No. 8, vol. X, 1915.



A *B* *C*

Fig. 4.—Three pages from a photometrist's notebook. *A*—The description. *B*—Map. *C*—Data.

Fig. 7.—A self-leveling test-plate.

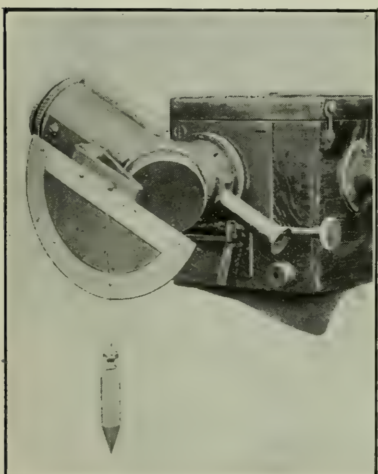


Fig. 8.—Protractor, plumb-bob and level.

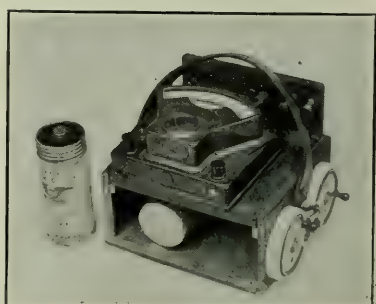


Fig. 5.—Ammeter rheostat and dry cells.

necessary to establish a level for the test-plate and maintain it. This is a simple matter in interiors where a level floor may be relied upon. In other cases, such as street lighting where the level has to be re-established at each station, and a reflecting test-plate is employed, a self-leveling test-plate is a great convenience.

Associated Candlepower Measurements.—Where a complete knowledge of the facts is desired, an intelligent discussion of results is impracticable if the light flux produced by the sources is unknown.

BRIGHTNESS.

Many installations may prove thoroughly satisfactory in that the intensity is all that is required, and the uniformity good, but there may be objects reflecting specularly or brightly illuminated areas within the immediate line of vision, which make the result objectionable and fatiguing to the eyes. It is frequently found of considerable aid in studying an installation to measure the brightness of the various objects within the ordinary line of vision. It is sometimes advisable to measure the same object in the plane of incident light, and in a direction 90° removed from the plane of incident light; in other words, measure the brightness in the direction of highest intensity and lowest intensity. The percentage difference will afford some indication of the potentialities for glare due to specular reflection from objects, such as a polished top desk, glossy paper, etc.

The brightness of the glassware surrounding the illuminant and ceiling or wall against which it is viewed can be measured, and the data obtained may represent the characteristics of the installation from the standpoint of great and annoying contrasts.

The approximate reflecting qualities or any mat surface can be ascertained by comparing the brightness of the surface with the brightness of a reflecting test-plate. The reflection coefficient of the test-plate is known, therefore, the reflection coefficient of the surface may be computed.

Brightness Measurements.—To make brightness measurements with a portable photometer the plate is eliminated and the surface to be measured is viewed directly. In other words, the surface to be measured is one of the photometric surfaces to be compared with the standard surface in the photometer. The brightness of

a uniformly illuminated surface as indicated by the photometer scale is independent of the distance between the photometer and the surface. This is obvious as the brightness of a surface does not vary with distance. Also as the distance between the photometer and the surface increased so does the area viewed in the photometer increase.

Brightness may be expressed in Lamberts.[2]

$$L = \frac{F}{S}$$

L = Lamberts
F = Flux
S = Area in sq. cm.

MAINTENANCE OF PHOTOMETER.

The photometrist should satisfy himself as to the correctness of the constants of the photometer before employing it in serious work. The adjustment of the comparison lamp, the transmission of the absorbing screens, and the accuracy of the scale throughout its entire range should command his particular attention. This cannot be done unless there is available an adequate equipment for verifying the instrument. Such an equipment is essential not only for a first check of the instrument but must be on hand if maintained accuracy is to be had throughout the life of the instrument. Comparison lamps will change and the optical parts of an instrument may become dusty through inattention. The only efficient safeguard is to provide independent means of verifying the photometer.

Among means for verifying photometers are small standardizing attachments for the simple check of the instrument in service at one point on the scale. Such a check is, however, quite incomplete unless an independent means is employed for the electrical measurements. To use the same electrical instruments for the photometer lamp is not good practise. For a verification of the other constants of the instrument more elaborate means must be provided.

The absorbing screens may be checked approximately at any one time during a test by finding some point where a fairly constant illumination can be had of such intensity that it may be

[2] See 1915 report of the Committee on Nomenclature and Standards of the I. E. S.

read both with and without the screen. In case of the use of two or more screens a darker screen can be verified by securing some other illumination which may be read with first the light screen and then the dark, thus securing the values for one screen in terms of the other.

ACCESSORIES.

There are a number of accessories to a portable photometer some of which are necessary, others simply convenient or conducive to greater accuracy. A few of these accessories are cited below, divided into two groups, essentials, and those conducive to greater accuracy.

Essentials	Aids to convenience or accuracy
Note-book	Standardizing equipment
Batteries or other supply	Self leveling test-plate
Electrical instrument	Color screens
Tripod	Telescope and cross-hairs
Plumb-bob	Protractor, plumb-bob and level
Tape	Slide rule
	Chalk

Note-Book.—The keeping of a photometrist's note-book is very important, as in many cases the small details which are often overlooked are of vital importance in the discussion of results. An aid to this end is a blank form divided into numerous headings and to be filled in during the test. The following is a sheet from a photometrist's note-book (see Fig. 4). The note-book page should be ruled in cross section as an aid in making maps.

Electrical Instrument.—All modern portable photometers employ electric comparison lamps. They must be kept at the standardization values if the work is to be accurate. It is a characteristic of the tungsten filament lamp that 1 per cent. variation in the impressed voltage occasions a change in candlepower of about 5 per cent., and 1 per cent. change in the current occasions a change in candlepower of about 10 per cent. Errors in indicating electrical instruments used with photometers are therefore multiplied by large factors in the resultant photometric values. Thus precision in the electrical instrument becomes very important. Unfortunately, it is the current practise to employ with portable photometers electrical instruments which in themselves are either of insufficient precision or which in their use are not handled with

sufficient care to obtain proper precision. It is to be feared that many illumination measurements suffer in consequence of this. It is conservative to say that an accuracy of 0.2 per cent. ought to be attained in voltmeters or ammeters used in portable work.

Most portable voltmeters and ammeters are not compensated for temperature changes sufficiently for work where extremes of temperature prevail. If photometric equipment is to be used in such cases the temperature of the indicating electrical instrument should be determined and the corrections should be applied. Another source of error encountered through the use of electrical instruments is that due to the influence of stray fields or the shunting of the instrument field. Care should therefore be taken to avoid placing the instrument on or near magnetic metals, such as resting the meter on the floor or sidewalk over iron beams. With the usual portable voltmeter and ammeters 0.2 per cent. accuracy can be obtained only if the error of the instrument is known and the instrument is handled and read most carefully.

Different portable photometers require different potentials for their operation, but the majority use a low volt comparison lamp (3-6 volts) which may be operated on either a small storage battery or on dry cells. If the lamp does not require more than 0.2 to 0.3 ampere dry cells will be found very satisfactory, and for convenience the screw top cell is preferable. As a measuring instrument a well compensated ammeter is preferable to a voltmeter as the photometer leads can be as long or as short as convenience requires without changing the electrical values in the lamp, Fig. 5. In some photometers the regulation of a comparison lamp is accomplished by means of a Wheatstone bridge. The resistance of a tungsten filament varies with the temperature. With three fixed arms in the bridge and the lamp for the fourth, the bridge will balance only when the lamp is at the proper resistance or the proper current is passing through the lamp. This device may be used as an accessory or part of the instrument. If as an accessory it must be attached to the photometer so that there is a minimum of wire of low resistance between the device and the lamp, thus obviating errors due to change in temperature of the leads. A low resistance galvanometer or low resistance high sensibility telephone may be used with excellent results as an in-

dicator for securing a balance. With sensitive galvonometer changes in current may be detected to less than 0.01 of 1 per cent.

Tripod.—A great deal of the work in which a portable photometer is required is done with the photometer mounted on a tripod, the measurements being made in a given plane. As the photometer is moved from station to station it is not convenient to re-level each time. Therefore a tripod with rigid legs is most convenient. For street work with uneven surfaces, however, it is essential that the legs be adjustable.

Plumb-bob.—In any photometric measurements where it is essential to establish test stations having a definite location with reference to the light source, it is necessary to establish accurately a point immediately beneath the source. A quick method is the use of a plumb-bob suspended from the center of an opaque ring. To determine the point directly beneath the light source the plumb-bob must fall in the center of the illuminated area of light falling through the ring or at the center of the shadow of the ring (see Fig. 6).

Tape.—For computations a tape divided in tenths and hundredths of feet is found very helpful.

AIDS TO CONVENIENCE AND ACCURACY.

Standardizing Equipment.—As previously stated photometers must be frequently verified, and a small standardizing equipment for portable photometers furnishes a verification during test. This equipment, of course, must be verified itself, but as it is used for only a small fraction of the time that the photometer is used, it should remain constant for a long period. These standardizing equipments may be either self-contained, using the Wheatstone bridge principle, or may make use of the energy supply and meter used for the photometer. This later method has the disadvantage of rendering inaccurate results, if there is any change in the indicating instrument.

Self-Leveling Test-Plate.—For horizontal illumination values where a level floor or street are not available the self-leveling test-plate proves a great time saver. In case of high winds this device is equipped with a lock, but when the lock is used care should be taken to relevel the test-plate at each station. Fig. 7.

Color Filters.—Photometric accuracy depends largely upon a

close color match between the test and comparison field and an aid in promoting accuracy in measuring illuminants of a different color than the comparison lamp is a set of color filters. While it is difficult to match every light source, an approximate match can be secured with a few filters. The transmission values of these filters should be determined by comparison with standardized filters, and wherever practicable the filters should be placed between the comparison lamp and the photometer head. Thus a known flux of light is allowed to pass regardless of the color components of the test source. The objection to the use of color filters on the test side of a photometer however is more theoretical than practical.

Telescope.—Cross Hairs.—A simple short focus telescope with cross hairs forms a convenient apparatus for aligning the photometer. This can be made either a part of the photometer optical system or be mounted adjacent and parallel to the optical system.

Protractor and Plumb-Bob and Level.—The convenience of this device has been discussed in the determination of angles for candlepower measurements. It is also an aid in establishing street levels and street grades as well as securing building heights, tree heights, etc. (Fig. 8).

DISCUSSION OF RESULTS.

When a survey has been completed and the time comes to draw conclusions from the test data there are a number of considerations which it is well to remember. In the first place the purpose of the survey should be kept clearly in mind and the photometrist should be satisfied that the measurements are such in number and time as will accomplish this purpose. It is important to be sure that the measurements have been made in the plane or planes whose illumination is important; that the installation is typical of any installations which the conclusions may affect; that the operating conditions are typical and, in general, that there is no reason why the indications of the test should not be taken at their face value.

Test results invariably are subject to errors or to deviation from absolute accuracy. Each element which contributes to the final result possess liability to error. The photometer, the electrical instrument, the observer, each departs from absolute ac-

curacy, and the individual errors combine to constitute the error of the final result. The procedure, therefore, is to ascertain or estimate the extent of such individual errors, and to make certain that no errors are present in the final results which are large enough to vitiate the conclusions. Before results are accepted the accuracy of the indication of the photometer with the instrument with which it has been used should be determined to a certainty, and it is good practise to recalibrate the photometer with its electrical instruments after as well as before the test, in order to obtain assurance on this score.

In work of this class there are so many possibilities of error that all reasonable means ought to be availed of to check the results. No opportunity should be neglected to compare measurements with those obtained with another equipment. Experience with tests in similar installations should be brought to bear to ascertain if the results appear reasonable. Where the flux produced by the lamps has been ascertained, and illumination measurements have been made on a particular plane, the ratio of flux delivered to flux produced should be computed in order to determine if the "efficiency of utilization" appears to be reasonable.

Finally when accuracy has been assured and conclusions are drawn from a test, it is important to confine such conclusions to the particular test under discussion. All that can be said without qualification is that the result and the conclusions as obtained apply to a particular installation, a particular set of operating conditions, and a particular time. Before the conclusions may be assumed to be applicable to any other installation, any other set of operating conditions or any other time, assurance must be had that no differences exist which would alter the results in any particular capable of changing the conclusions.

DISCUSSION.

MR. W. A. DURGIN: Those of us who are more or less in the business of selling illumination which shall be permanently satisfactory are very glad to have this sort of paper published. Illumination questions are much befogged by assertions and discussions based on readings made by some inexperienced person with a portable photometer borrowed over night from a central station

company or other unwilling accomplice. It is to be hoped that this paper will give much publicity to the need of specialized experience and skill, if data of any real value is to be secured.

A few accessories not mentioned in the paper have been found helpful.

First in importance is a small truck similar to that shown in Fig. 3 in Messrs. Harrison and Anderson's paper[1] which is to be read at this convention. We have used such a truck with smaller casters for some time in all interior and side walk tests and recommend it especially for the ease with which cross wires on the base can be used to quickly fix the location at stations. The arrangement is much more convenient than the usual swinging plumb-bob.

Improved absorption screens offer another convenience. These are available in sets having definite coefficients of 0.1, 0.01 and 0.001 transmission accurate to ½ per cent.; a notable advance over the haphazard coefficients generally in use.

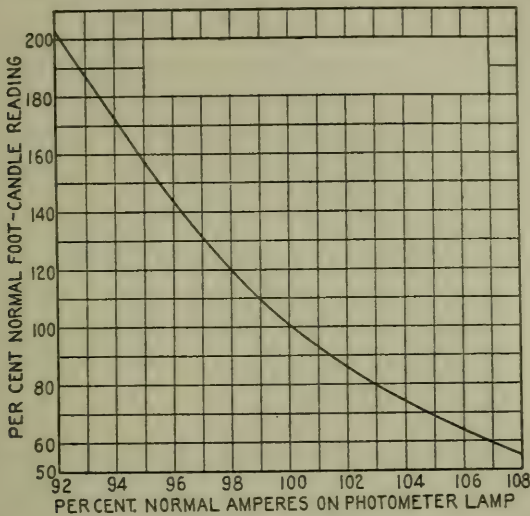
In standardizing the photometer, we obtain more consistent results by leaving the current adjustment unchanged and determining from time to time the constant factor to be applied to the foot-candle readings. The use of a factor presents another advantage since in important work we find it necessary to use duplicate equipment with two sets of observers and, with correction factor standardization, the two sets of uncorrected observations are sufficiently different to prevent bias in reading.

Some discussion of the means of checking brightness coefficient perhaps would add to the great value of the paper. There is considerable doubt in many testers' minds as to just what brightness constant means at the photometer screen and as to whether the same calibration correction constant applies to it as to the foot-candle reading.

Mr. L. C. Porter: Mr. Little calls attention to the necessity of accurate measurement of the current in standard lamps, and I think that that should be emphasized a little more. We find in our work that one of the great sources of error is in not getting the standard lamp in our photometer to operate at exactly the proper current value. Some tests which I have made indicate

[1] Trans. I. E. S., No. 9, vol. X, 1915.

that a change of about one one-hundredth of an ampere through the standard lamp will result in something like a 20 per cent. change in foot-candles read on our photometer. The accompanying curve shows a calibration test run on one lamp.



Calibration curve of a portable photometer.

We have found that it is hardly practicable to hold the voltage on the photometer lamp. The voltmeter leads are soldered to the lamp socket and even with correct voltage there the lamp may not be operating correctly, due to contact resistance between the lamp base and the socket. It is more accurate to read amperes, and in order to do that we use a mirrored needle milli-voltmeter with a scale divided into 150 divisions, and a six-tenths ampere shunt. In that way we can obtain a very accurate current value, and changing the leads used does not entail a voltage drop, contact resistance, etc.

Speaking of the use of dry batteries—we use dry batteries a great deal for working portable photometers, but find that almost every time the batteries are moved we have to re-set the milli-voltmeter. After the lamp has burned a short time, the batteries seem to hold fairly steady for a considerable length of time, if not moved, but if the batteries are moved, it seems to affect the current and we have to make readjustments.

Another field in which portable photometers are being used to a considerable extent is the measuring of searchlights, floodlights, stereopticons, motion picture machines, etc.; in fact, any projected light. That is very easily accomplished by two methods: a searchlight may be set on a table which can be rotated accurately; and the photometer held in one position or one may draw an arc of a circle and measure off stations about a foot apart across the beam of the searchlight and move the photometer across the beam. In doing that, it is well to make sure that the tube of the photometer points directly at the searchlight. It can be easily located by taking off the diffusion plate on the end of the tube and centering the searchlight in the photometer (one can see it in the center of the mirror very clearly and can center it in that way) then replace the diffusing glass and read the foot-candle value. Multiplying that by the square of the distance from the light source to the photometer, one obtains the beam candlepower of the searchlight.

Mr. Earl A. Anderson: The discussion of the precautions necessary in performing illumination tests with a portable photometer as given in this paper is of special value for, as Mr. Durgin has suggested, very often portable photometers have been used by individuals unacquainted with the necessary precautions. Perhaps the first essential in reliable photometric work is careful and frequent standardization of the comparison lamp. Where stationary photometers are used, means for accomplishing this are provided as a matter of course and for portable photometers repeated calibration is even more necessary on account of the more delicate nature of the apparatus and lamp, and the unavoidable jars and disturbances in carrying the instrument about.

Recognizing the importance of facilitating checks of the portable instruments the engineering department of the National Lamp Works of the General Electric Company at Nela Park has found it desirable to fit up a special photometric bench for this purpose. A standard 125 in. bar is arranged with a device for readily clamping into a fixed position at one end the illuminometer which is to be checked. Standard lamps of high and low candlepower are provided and the illumination can be conveniently varied over a wide range by altering the position of the

standard lamp carriage. Calculations are simplified by the use of a distance scale calibrated to read directly in foot-candles upon the test-plate.

A bench of this kind with the proper indicating instruments in place enables the operator to take the number of observations necessary for complete standardization of his instrument in a very short period of time. In addition to the large saving in time introduced, a permanent routine method for checking the portable photometer eliminates the doubt existent in test results where standardization must be made with a temporary set-up.

Mr. S. L. E. Rose: It seems to me that one of the most important things here is the note-book and data taken during the test. It is easy enough to watch the operator while he is in the laboratory calibrating his instruments, and I don't think Mr. Little's paper probably intended to cover the work done in the laboratory; but when the operator gets outside, it has been our experience that he will often come back with insufficient data to properly interpret the results, and it is very advisable to have a data sheet calling for what is wanted, and then all the operator has to do is to fill in these blanks and when he gets back it is easy enough to interpret the results. Another thing Mr. Little has called attention to, which is important, is the experience necessary to pick out the proper representative sections in the lighting installation under test. Anyone with ordinary intelligence and some instruction can take readings on a portable photometer; but to go out and get the data properly noted down so that one can have all the required conditions has been the greatest fault we have found with the operator. Another great aid which we have often used and which we have found advisable is, where possible, to take a photograph of the installation. This will often give a lot of data possibly not called for, and the operator has not thought to jot down.

Mr. G. H. Stickney: From my experience and observation of tests made with illumination photometers, I believe much data is gathered, and some is published, in which indeterminate errors exist. Such errors may render data worse than valueless, in making it misleading.

I am somewhat apprehensive of tests made in interiors, especi-

ally with reflecting side walls, when the opaque test-plate is used, since such plates must be observed from above. Even though the observer may not cast a direct shadow on the test-plate, it is often impracticable to tell whether or not an appreciable amount of light, reflected from side walls or other objects, is being intercepted.

Another source of error which, though small, may under some conditions be sufficient to give misleading results, is the failure of most test-plates to adequately evaluate light falling at angles approaching the horizontal. It has sometimes seemed to me that this error has been responsible in the past for the tendency of illumination tests to favor lighting units in which a large part of the flux is delivered at steep angles.

Illumination tests made by amateurs are often of little value because conditions are not made definite or are not properly recorded. For example, the observers may be careless as to whether all the lamps in the installation are of the designated rating, whether they are old or new, clean or dirty, or are operated at the correct voltage.

I quite agree that, on account of convenience and simplicity, too much weight has been given to the intensity in a horizontal reference plane. Often the intensity in some particular oblique plane, or rather a number of such planes, is a more correct measure of the value of the illumination. To take care of such conditions we have sometimes supplemented readings in the reference planes by a measurement of the illumination falling on particular surfaces where strong illumination is especially required.

In a way brightness measurements, which are becoming more and more common, carry out the same idea, with the additional value of including the effect of the surface.

The importance of illumination and brightness measurements in connection with certain problems is so great that every effort should be made to avoid any discrediting of such measurements due to careless or imperfect work.

In measuring the beam candlepower of projected light—say, from a parabolic reflector—it is important that the observing stations should be far enough away from the reflector to insure homogeneity of the beam. In this connection it is well to specify

the distances at which measurements are made in giving the data. Where practicable it is preferable to measure it at a distance corresponding approximately to the principal use of the light.

NORMAN MACBETH: It hardly seems possible that among all the papers presented before this Society, that this is the first paper on this most important subject. I know of no one better qualified by experience than Mr. Little, and I only regret that these results were not on record several years ago. I am not altogether in agreement with Mr. Little on some of the points brought up in discussions of this kind from time to time, and particularly on what I feel is an over-capitalization of the illumination measurements taken to secure the so-called utilization efficiencies. That this consideration is uppermost is due very largely to the general use in the past of the transmitting test-plate and very largely also because in the investigations which Mr. Little has been required to make these values were desired. I have always felt that the largest field, by far, for the portable photometer or illuminometer is in investigations of the brightness of the various surfaces with which we have to deal in all lighting installations.

The apparatus which he has perfected should be considered as part of the regular equipment as it is all very valuable and necessary. The manufacturers of photometers should include some such devices with every instrument sold.

The telescope plum-bob and protractor illustrated in Fig. 8 is especially interesting. A couple of years ago in the development of an illuminometer I designed somewhat similar parts, but before the construction was completed we found that a clinometer made by an English concern would do all we hoped for and certainly at a cost much less considering the greater number of clinometers made as compared with the more limited market for a special instrument to be made for use with an illuminometer. This instrument was a beautiful piece of work and required but a slight addition to adapt it to our work. Furthermore, its cost—twenty to twenty-five dollars—is considerably less than it could be produced for in limited quantities.

Mention is made of a standardizing equipment. I believe that a device for this purpose is most important; and in my experience

I know of no other device as comforting and tending to save time and generally facilitate illumination measurements and without the incident worry as to whether the working standard lamp is in an unknown condition.

This paper will be especially valuable in the Transactions. The matter is of the greatest importance and has been covered in an authoratative detailed manner which can only result in a better understanding of this subject. Now that we have received full sanction of that necessary brightness unit, the lambert, I hope to see papers before this association having to do with illumination measurements on the surfaces which are of the greatest importance—those surfaces encountered by the eye in an interior—and with data on their brightness range we will have more real information as to what constitutes good illumination than is possible with our present data where only test-plate measurements have been taken. The test-plate values help in working backwards to repeat a given result where all other conditions of installation are similar. As this is an almost impossible combination, we should look forward to the day of more general recognition for illumination measurements of surfaces as they are in daily use.

Mr. Little says that "It is obvious that illumination measurements should be made in a plane, the illumination of which is the principle purpose of the installation. This refers to height of horizontal plane or to inclination of other planes which may be studied. In some cases it may be desirable to determine the flux density of the light incident on a surface inclined to the horizontal. As in the case of the study of the illumination of school desks, show windows, machinery, etc." I should like to ask, inasmuch as Mr. Little has stated the necessity of measurements taken with the operator below the test-plate, if he would also consider, that in all cases of school desks, etc. that the observer should occupy the same position as a pupil at a desk or a man working at machinery. We do not live in unfurnished rooms, and most of the illumination measurements here described were investigations tending to bring out the utilization efficiency of lamps, not the effectiveness of the lighting installation with people in the rooms. It is particularly in measurements of this kind that the body of the operator should occupy the same

position as an average occupant of a room or operator at a machine.

Mr. P. S. Millar: The novice in photometry rarely, if ever, considers himself capable of undertaking a photometric test utilizing well designed set-up laboratory apparatus. It is one of the unfortunate things about portable photometers that this same novice approaches their use with all kinds of confidence in his ability to make a photometric test and in the reliability of the results which he obtains. Because the instrument is smaller and less elaborate in appearance than laboratory apparatus, and because it is a simple matter to go through certain perfunctory motions and to get an indication on a scale, there is a tendency to assume that such process constitutes a photometric test. Those of us who are familiar with the facts appreciate, as the author has stated, that the requirements for care and the exercise of common sense in the use of these instruments probably surpass that which the ordinary practising photometrist is called upon to exercise in routine work under established conditions.

This paper and discussion have made it evident that there are two points of view regarding the use of portable photometers. The author's viewpoint is that of one who is engaged in testing work; his principal aim is to obtain accurate results from an engineering survey, the report of which is rendered to a client. He therefore avails himself of every practisable means of verifying the test and the results. When practicable he prefers to ascertain the total flux of light on some plane because the experienced photometrist or illuminating engineer can usually estimate fairly well what the average intensity of light on a given plane should be in any particular installation; and if the result is not in accord with such estimate, the reason for the difference must be ascertained. He makes it a point to obtain a measure of the light produced by the illuminants as a part of his attempt to tie together all the data of the installation into one consistent whole. When a test of this kind is completed the photometrist feels fairly certain that his results are reasonably correct, and this certainty arises not only from his knowledge that he has exercised care and intelligence in the conduct of the test but also from his knowledge that the various data of the installation are in a proper and consistent relation with one another.

This point of view by no means eliminates interest in and need for measurements at arbitrarily selected points both of illumination intensity and brightness. It, however, requires that these measurements be supplemented by the other measurements, which ought not to be eliminated if a definite engineering report is to be had on an installation.

The other point of view is that of a man who is doing illumination work. With a minimum of bother and in the shortest possible time he wants to know in general what the lighting conditions are. He wants to know the high and low extremes of intensity and brightness and gets a few values of the light here and there where he is particularly concerned with the conditions. The difficulty with such a survey is that the photometrist has no adequate means of verifying his determinations and conclusions. His results may be and often are quite erroneous, while there is nothing to indicate that such is the case. In such a survey the photometer may be wrongly calibrated, lamps which are providing the light may be operating at the wrong voltage and various features of the installation may be improper. The photometrist will not know the facts and his conclusions based on his results may be unwarranted.

If we could only compel every man who uses a portable photometer to go through the more extensive testing routine as well as to make the occasional haphazard measurements at points of special interest, photometric errors would be reduced and perhaps eliminated, because that man would soon learn the real fundamentals of photometric testing. It was not long ago that we had occasion to use a photometer whose absorption screens were erroneously calibrated by 10 to 20 per cent. Unless some of the precautions advocated in this paper had been taken, we would not have known that the instrument was erroneously calibrated.

Another reason favoring a systematic study of illumination installations is that only in that way can strict comparison be made between different lamps, different lighting equipments, etc. Where matters of commercial importance hinge on the results, it is very important that photometric tests reveal the facts, and a systematic study of the installation along the lines laid down in this paper is essential to correct conclusions in such cases.

One speaker has suggested that the photometrist may be substituted for a workman in respect to the shadow cast upon the work during a photometric test. In testing work it is a fundamental principle to separate as many variables as possible and to examine each from the influence of the other. Shadows constitute a very important variable and ought to be studied as shadows. The distribution of light in a room and its intensity should be measured, and then to determine the influence of shadows one should study those shadows with respect to direction and density under actual working conditions. It would be the simplest thing in the world for a photometrist either to draw improper conclusions regarding shadows while turning to arrive at the correct ones, or to purposely create improper conditions if the shadows were created by himself during the course of his testing.

Mr. A. H. Taylor: I would like to call attention to a few things which we have found in practise at the Bureau of Standards to be very fertile sources of error. One of these is in setting the voltage or current to its proper value. In practise it is best to use a meter with which you have practically full scale deflection for the proper setting of the lamp in the photometer. Some small meters, as you know, have no mirror backing, and it is possible with these to make a very appreciable error due to parallax. Another source of error is in estimating a fractional scale division. Instead of trying to get the setting of the needle to give the proper balance of photometer, it would be better to set the needle on the nearest even scale division, making necessary the application of a small correction factor to the results. This factor could be incorporated in the calculations in the laboratory after measurements have been made, and would eliminate this source of error. A method which we have used with success, one which does away with the necessity for application of a correction factor to results, is the use of a temporary scale line. When the photometer is standardized in the laboratory, and proper meter setting has been determined, a piece of gummed paper, having two fine ink lines ruled on opposite sides, so that one line is directly opposite the other, is pasted on the glass of the meter. It is so placed that the line on the paper, the needle, and the mirrored images of the needle and line on under side of paper are

in line. If the lines are ruled fine, meter adjustments can be made quickly and very accurately, and difference between observers in estimating fractional divisions are entirely eliminated. In using this method, however, it is evidently necessary to be certain that the meter casing is rigidly fastened so that there can be no relative movement between casing and scale. Additional ease of setting may be obtained by the use of a reading glass fixed in position over the scale.

In the *initial standardization* of the photometer it is desirable to make not less than ten to twenty photometer settings at the determined voltage, since the average of that number may be quite different from the average of only three or four readings. The additional readings are so easily made that the increased accuracy amply justifies the trouble.

In many portable photometers the field is far from uniform in intensity. Some observers say that they balance the whole field, and really do get very consistent results, even when the field is not uniform. However, with the same photometer, observers who confine their attention to a small portion of the field get differences in their readings by making balances at different parts of the field. Sometimes there is as much difference as 5 to 10 per cent. in settings taken at opposite sides of the photometer field. The observer who is to read the photometer should have this definitely in mind, and if he is reading only a small part of the field, as is sometimes the case, that is the part of the field which should be observed in standardizing the instrument.

Mr. W. F. Little (In reply): Mr. Durgin has referred to the caster truck for the photometer tripod. If a rigid tripod is used the test-plate may be located over one of the legs at the beginning of the test. Thus the photometer may be quickly and accurately located over the test station without a plumb-bob and, as the equipment is light, little time is lost in lifting it from station to station.

A sufficient number of check readings will under ordinary conditions prove sufficient to establish the representative values without a duplication of apparatus.

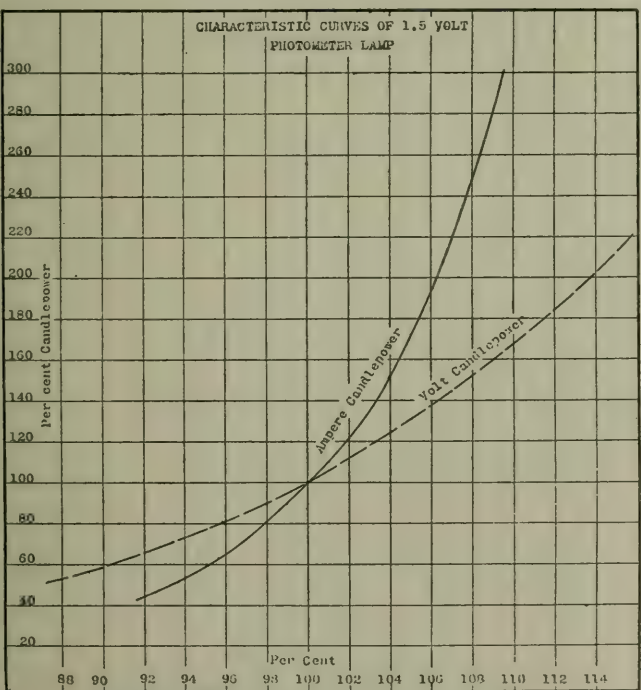
Applying a factor to the scale reading instead of changing the current on the photometer lamp to secure true values makes un-

necessary computation work. If the photometer is standardized and found to read incorrectly, the characteristic curve of the comparison lamp may be consulted and the current changed. A second series of readings at the new current value will produce a double check, and the calibration should be that much more accurate.

Calibration for brightness is quite difficult outside of a well-equipped photometric laboratory; therefore, it was not discussed in detail in this paper. It is, however, done as follows:

Standardize the photometer in foot-candles using a reflecting test-plate, then illuminate the test-plate (preferably from the rear to eliminate stray light) to a definite intensity (probably 50 foot-candles) and measure the illumination produced by it at a given distance (at least five times the plate diameter distance). From the distance and the illumination, compute brightness per unit area.

Once having standardized the photometer, a transmitting test-plate may be used as a secondary standard by measuring the brightness of its under surface with a known illumination produced on the outer surface.



Characteristic curve of 1.5-volt photometer lamp.

Mr. Porter speaks of the necessity of accurately holding the current of the photometer lamp. An examination of the characteristic curve of the lamp will further emphasize this point. The measuring instrument used for this purpose should have a long mirrored scale, and a shunt such that the meter indication is well toward the top of the scale. Long leads to the batteries obviate the necessity of frequent changes in their location.

Mr. Anderson refers to the process of standardization of the photometer. A quick and accurate method which has proved very satisfactory is to use a standard lamp of sufficient candle-power to produce 16 foot-candles on the transmitting test-plate at a distance of at least two feet and with the use of rotating sector disks the complete range of scale can be covered, including the absorption glasses.

Mr. Taylor has spoken of errors caused by an insufficient number of readings and inaccuracies in reading the electrical instrument. These and many other errors (as mentioned in the paper) creep into portable photometry. Experience alone will suffice to place them in their order of importance, and the photometer operator should use judgment and discretion in the performance of the work.

HOW CAN GAS AND ELECTRIC COMPANIES UNDER ONE MANAGEMENT RENDER THE BEST LIGHT SERVICE?*

BY A. B. SPAULDING AND N. H. POTTER.

Synopsis: This paper treats from the commercial standpoint only the subject of service to the customer by gas and electric companies under one management. It emphasizes the importance of service to the customer, and outlines the question of service from a practical standpoint. In discussing the selling force necessary for the proper handling of lighting business, the authors recommend the employment of specialists on gas illumination and specialists on electric illumination. The education of the salesmen is considered and a successful local educational course outlined. The education of the customer is discussed from the standpoints of the manufacturer of appliances and the lighting company. The relation between the representative and the customer is of special importance and particular stress is laid on the matter of maintenance of lighting units, which maintenance is in reality the "keynote of service."

One of the important subjects to-day among gas and electric companies is "How can the best service be given?" The engineering phases of this question have received marked attention, and the improvement in design and operation of gas and electric plants has increased the confidence of the public in the efficiency of these plants.

This paper deals with the rendering of service after the product is delivered, or beyond the meter. There are differences of opinion as to how this can best be done.

Among the trio of products of gas and electric companies—light, heat and power—light has always received the first place. Upon the selling of this product depended the initial success of all gas and electric companies; and the early history of both industries is bound up inseparably with the development of their lighting business.

There has been a radical change in the methods and personnel of the selling force. Heretofore gas and electric energy were the points of discussion with the consumer; but now illumination is

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

the topic. Instead of so many cubic feet of gas or watts of energy, illumination is being sold.

On account of this advancement the illuminating engineer has developed, and the Illuminating Engineering Society is an outcome of the desire of gas and electric companies and manufacturers to render the public a service by united effort toward improved illumination.

The present estimate of the work of any man must be, "How much does he produce,"? and if any representative, no matter what his printed title may be, does not produce, he is not efficient.

Selling and service should be synonymous, and service has various phases. In order to render it intelligently it is essential, first, that the representative be capable of laying out and supervising a lighting installation; second, that the consumer be educated to appreciate the difference between proper and improper lighting, insofar as the value of proper lighting to his business is concerned.

Service does not necessarily mean the reduction of bills; it may and often does result in an increase in the amount of business with customers. Proper illumination is desired and must be the primary factor in the discussion of cost, not only of electricity and gas supplied, but of fixtures and first installation. Service, therefore, means the providing of the illumination best suited to each customer at minimum cost.

Both the representative of lighting companies and the public must be educated to the value, use and maintenance of a lighting installation.

GAS AND ELECTRIC SPECIALISTS ON THE SALE OF ILLUMINATION.

The writers believe that with gas and electric companies under one management specialists on gas illumination and specialists on electric illumination are productive of the best results, particularly as regards service to the customer. This method is in reality intensive selling and each man becomes an expert in either gas or electric illumination. Both men are selling the same thing, *viz.*, illumination; and unconsciously perhaps, each man picks out the most likely prospects.

It would seem that there is no good reason for a gas or electric company under one management adopting a policy which en-

courages only one source of supply. The duty of such a company is not to pre-determine what source to sell, but to give the customer the benefit of the best advice and leave to him the decision.

That two sources are better than one is certain where gas and electric units are installed for general illumination. The units should harmonize with each other and with their surroundings. The only question, which might influence the installation of a single source, would be its adaptability.

The argument has been advanced that by having one man sell both gas and electric illumination, the selling force could be cut in half. This is not true if the business is to be taken care of properly.

It has been contended that the consumer is confused by having two men advising different sources of supply. This may be true where companies are under separate management and competition dictates a policy of "Get business anyway,—but get it," rather than a policy of real service to the consumer. With a company under one management the consumer is not confused by having information on both gas and electric illumination from different men.

The customer should be credited with common sense and have the privilege of choice. By having both sides advanced to him by experts he is able to consider economy, convenience, safety, etc., and in the end be sure that he is getting that method of illumination best suited to his needs.

Summing up we find that separate gas and electric lighting representatives are in the end no more expensive than combination representatives. There is absolutely no question that this separation does stimulate the trade in a healthy manner. Each salesman becomes more proficient in the art of gas or electric illumination as the case may be. He has cooperative competition and will necessarily have to watch his installations more closely. He is also forced to make proper installations and to render proper service after installation is made; otherwise he is likely to have "lost business" charged up against him, and he keeps in closer touch with improvements in his particular line.

A man selling both gas and electricity is too prone to follow the path of least resistance and to think, "If I don't sell gas, I will

sell electricity," with the result that a desire for better illumination is not created and therefore the best service is not given.

EDUCATION OF SALESMEN.

Lighting representatives should have good appearance, personality, and selling ability, together with a knowledge of the principles of illumination. The salesman should make a general survey of his territory and become familiar with its conditions. He should make periodic tours after dark in the store section. He can then pick out the improperly lighted stores and by one night's work of this sort obtain sufficient leads to keep him busy for several days. The writers know of several instances where salesmen living out of town had never seen their territory illuminated. After making night inspections and following up leads thus obtained, the volume of store business from their particular sections showed a marked increase, and improved installations also resulted.

The representative should visit other districts than his own and, where possible, other cities and towns, thus acquainting himself with conditions, perhaps different than those in his territory, which will enable him to handle more successfully new and similar problems as they arise.

The lighting representative should, if he expects to become more valuable to his company, do everything in his power to increase his knowledge of illumination and other branches of the business. This can be brought about by his becoming a member of the Illuminating Engineering Society, National Electric Light Association and National Commercial Gas Association, through which he obtains at first hand, knowledge of all advancements in the art of illumination as well as other subjects, particularly so if he take advantage of the correspondence courses now offered by the last two societies. If he be fortunate enough to have a local section of any of these associations in his vicinity, he will derive great benefits by attending all its meetings and taking an active part in the discussions. In addition he will become acquainted with other men in the same line, receive the benefits of their personal knowledge and experience, and be able to reciprocate.

There are other means at hand of increasing one's knowledge and keeping abreast of the times, *viz.*, reading periodicals dealing

with all branches of illumination and the advertising literature sent out by manufacturers, which contains an education in itself. This literature should be studied, not merely read; for here is a fruitful field of knowledge. Up-to-date data can be obtained by having one's name placed on the mailing lists of manufacturers.

The sales manager in charge of these men should hold regular meetings for the discussion of illuminating problems. Arrangements should be made for visits to places like the testing laboratories and various fixture and lamp works. When some particularly fine installation has been made in the vicinity, a party should be made up to inspect and discuss it when it is lighted.

The company itself has a duty to perform in the education of its representatives. It should encourage the men to study and show that their efforts are appreciated.

The Public Service Gas Company and the Public Service Electric Company of New Jersey have given courses to develop the desire for further knowledge on the part of the men.

The following course has been given by the Public Service Electric Company.

(1) "The Central Station Salesman; His Duties, Troubles and Needs."
(2) "Lamps; Their Manufacture and Characteristics." (Lecture by representative of a lamp company, and visit to factory.)
(3) "Light: Its Production; Its Properties. Some Laws of Light."
(4) "Measurement of Light and Illumination." (Visit to testing laboratories.)
(5) "Reflectors, Shades and Diffusing Globes; Their Use and Abuse."
(6) "Direct and Semi-indirect Illumination."
(7) "Location of Units: General Consideration."
(8) "Residence Lighting."
(9) "Store Lighting."
(10) "Industrial Lighting."
(11) "Electrical Advertising."
(12) "Kw-h. Sales and New Business."
(13) "Wiring." (By a contractor.)
(14) "Review."

EDUCATION OF THE CUSTOMER.

The main object of a storekeeper for instance is to sell merchandise; he has no desire to become an illuminating engineer; but he is desirous of having his store and windows properly illuminated, provided of course, he is an up-to-date merchant. In the event of his being behind the times—and there are many of that kind—in fact, they are the ones who make up the best list of prospects—he should be taught that a properly lighted store and window are absolutely necessary for success in selling merchandise.

The desire to have a properly lighted window, store, factory or home lies dormant in every man, and under stimulus he will unconsciously start a course of self-education by asking questions and observing other installations and perhaps reading.

The company should send advertising literature acquainting him with the proper method of using lighting units. For obvious reasons this literature should be absolutely non-technical. It should be attractive in appearance and so written that it will hold the attention from cover to cover.

The manufacturer's representative should present the subject of illumination first, and, secondly, the wares he is selling. The architect, builder, electrician and gas fitter should be educated by both the company and the manufacturer in order that they may in turn do their part toward the education of the prospective customer.

With these three different sources of information for the customer properly co-ordinated, there would be little or no reason for the absence of good lighting installations.

RELATION OF REPRESENTATIVE AND CUSTOMER.

As has been stated, the first consideration in this relation is the impressing upon the consumer the value of proper illumination. Poor installations have been made in every town and one of the present difficulties is to have the customer realize the importance of a good installation.

If the manufacturers of lamps and accessories were to deal entirely through the gas and electric company whose sole idea is proper illumination, or at least submit for the approval of these companies the unit or accessory which is to be installed for a customer, relations with the consumer would be much improved.

Cheap and inefficient gas and electric units have caused the gas and electric companies much trouble. Such units are often sold with an argument to the effect that the gas or electric company is robbing the consumer and will not sell such units because they reduce the company's revenue. On account of such conflicting suggestions to the customer it has been found advisable to demonstrate the correctness of recommendations made. The Public Service Electric Company has been using for some time very successfully window demonstration sets. These are made up in portable form and consist of 4-ft. (1.23 m.) sections of pipe with five outlets. Twenty-five, 40, or 60 watt lamps with proper reflectors may be connected and in the case of large windows several sets may be hung in line. The sets are hung by the representatives in a few minutes by the use of screw eyes and picture wire, and connections made by lamp cord to any available lamp socket. As may be seen the outfit is very flexible and may be made to fit almost any window condition. It may be advisable to change these outfits to accommodate the gas-filled lamp on account of its better color value and increased efficiency.

The demonstration not only shows the display to better advantage, but the merchant gives more attention to the dressing of his windows, which, combined with good lighting, results in increased sales of his merchandise, thereby bringing the company and customer closer together, the latter realizing that the company has rendered real service. By advising customers both as to lighting and dressing of their windows, it has been possible to have more light used not only for illumination, but as part of merchandise displays. For instance, a customer who operates a piano store desired a special dressing for his window and the display installed was a reproduction of a painting entitled "Just a Song at Twilight." A reproduction of the original painting was placed in the window and properly lighted. In one corner of the window was a woman playing a baby grand piano and on the other side a fireplace, in front of which the husband sat holding a child in his arms. At one side of the room was a window through which was projected light approximating moonlight. From the fireplace was projected light of a ruddy hue. Alternately the lighting of the window itself was flashed on, then the effect as noted.

Since the installation of this window the Public Service Electric Company has been requested many times to dress other windows, and in every case where this has been done, the number of observers of the window has been more than doubled, and in the case of the window mentioned the observers were increasd 1,200 per cent. between 5 and 11 o'clock at night.

These installations, which are allowed to remain about a week, usually convince customers of their value and lead to the installation of permanent outfits.

Factory lighting may be handled in the same way. Demonstrations of either gas or electric lighting have been in many cases the closing arguments for the sale of better lighting.

After the installation is laid out, it is necessary that the representative should closely follow the development in the work to see that the suggestions of the electrician or plumber are not such as to spoil the desired results. It often occurs that the customer accepting advice on changes in position of outlets and accessories secures an incorrect installation and blames the representative for whatever unsatisfactory result may ensue.

The representative's responsibility does not end with the demonstration. It is his duty to lay out the proper units, supervising their installation and see that prompt service is rendered.

At this point the real service in lighting installations begins. Once connected to the company's supply, service to the customer never ends, and that all important question of maintenance begins.

In the case of electric lighting, maintenance is more or less a matter of education. The customer should be taught first that electric lamps have a useful life and that after a certain period it is economy to throw away old and purchase new lamps. Secondly, reflectors decrease in efficiency with the accumulation of dust, and like the plate glass window in the store must be cleaned periodically.

The customer usually promises to attend to these details which are in reality a part of his regular house cleaning, but the drop in efficiency of the loss in illumination is by such small steps, that it is never noticeable from day to day, and the customer being intent on selling goods, gives little or no attention to the importance of maintenance.

The lighting salesman may continue rendering service by calling attention to any blackened lamps, dirty reflectors, etc. By stating to the customer that this is his (the salesmen's) installation, that he is proud of it, but that it cannot come up to his guarantee unless properly cared for, the customer is usually awakened to his responsibility in the matter and the habit of periodic inspection and cleaning is formed.

In the case of a gas installation, maintenance is also a very important matter. Thoughtlessness or carelessness is the reason for depreciation in lighting value. Again the daily change or drop in efficiency is so small as to be unnoticeable. Many customers through not having time or not appreciating this drop in efficiency continue using old or broken mantles with the result that very poor service is obtained from the unit.

Gas companies have been trying for years to educate customers to give proper attention to their lighting units, but in many cases it is almost a hopeless task, with the result that in many instances companies have launched maintenance departments to do for the customer what he does not seem to care to do for himself. Probably the day is not far off when all gas companies will have to maintain all customer's lighting installations in order to insure proper illumination.

At this point the writers desire to mention a system of residence maintenance service by which customers receive periodic inspections of all lighting units. This service includes cleaning of glassware and adjustment of burners without any charge. The men engaged in this work also carry samples of the latest types of lamps and a full line of repair parts and accessories. If new material is sold to replace that which is broken, no charge is made other than the regular selling price of such material. By this plan the company is enabled to attend to all complaints received before 3 p. m. the same day. This plan is being tried out by the Public Service Gas Company in one city in New Jersey with such good results that in a very short time it is expected that the sale of repair parts and additional units will alone make this department self sustaining, not to mention the increased satisfaction on the part of the consumer nor the added consumption derived by having more units in good working order. This department is productive of many sales and materially strengthens the selling

organization of the company. The aforementioned plan is similar to the so-called Toronto Plan with which many of you are no doubt familiar.

It is the opinion of the writers that in order that a gas and electric company under one management may give the best lighting service, separate representatives who are specialists in the application of each lighting source should be employed. These representatives should be encouraged to keep in touch with the science of illuminating engineering and the most advanced thought in modern salesmanship. The company should lead the customer to an intelligent appreciation of proper illumination and by the adoption of a maintenance service should make him feel that the company is genuinely interested in his continued satisfaction.

DISCUSSION.

MR. PRESTON S. MILLAR: I think the work of electric and gas supply companies, their engineering and operation up to the meter, is likely to be much better standardized in the several communities than are the conditions in the consumers' premises beyond the meter; all sorts of policies obtain among such companies in regard to the treatment of the consumer in his own installation. The service, whether gas or electricity, is translated into illumination by lamps and fixtures.

Gas lamps are in general not what they ought to be in residence lighting. Open flame burners are still used very largely and the possibilities of gas for illuminating purposes are not being realized.

I have recently had the privilege of conducting a survey to obtain what condition the electric lamps are in when they are offered to central station customers. A great many tungsten filament lamps are distinctly inferior to the standard. The condition of some lamps that are offered to the consumer by reputable dealers and contractors, and by other selling agencies ranging down to the five and ten cent store, is such as ought to command the attention of every central station. Unless care is taken by the central station as to the quality of lamps that are sold to their consumers, electric lighting is likely to get into some of the difficulties that gas lighting is laboring under.

In the matter of fixtures I have often wondered if gas and electric supply companies could not do a great deal in the way of cultivating good public opinion, pleasing the customer and promoting the sale of gas and electricity by making pleasing fixtures available on attractive terms. I think that men should be employed to select and design artistic fixtures which will give pleasing effects, fixtures that will bring out the decorations of the room to the best advantage, diffuse and tint the light so that it will be pleasing to the eye and comfortable. In so doing there may be an increase in the customer's bill, but this will not be objectionable to the customer if the lighting pleases him. The experience I have had indicates that once the lighting is improved in a house in the manner I have indicated, the customer is willing to pay a larger monthly bill because he has more pleasing lighting and he would not go back to the lower bill and the inferior lighting for anything. I know of very little that is being done in the way of cultivating in this way the opportunities which are offered.

Finally I want to compliment the authors of the paper; it seems to me that it is just the kind of a paper that the Illuminating Engineering Society wants to see brought to the attention of the gas and electric supply companies throughout the country and I would like to recommend that the paper be printed for general distribution among gas and electric companies; I think it would do a great deal of good.

Mr. R. B. Ely: I believe the lighting companies are more inclined to the belief of selling a service rather than gas or wattage and with that in view they are trying to furnish all, that their advertising departments are talking about, such as proper illumination and upkeep of system to obtain the maximum results at a minimum cost. I would like to inquire as to how far the Public Service Company has gone in checking up the recommendations of their representatives, whether they follow the recommendations up with any tests, and to what extent they are going in the matter of demonstration, the demonstration of fixtures for the interior of stores, both gas and electric, and the period of time of such demonstrations. I would also like to inquire whether the men on this particular end of the work, the

lighting service work look after the commercial conditions, such as contracts, to see that their consumers are receiving the best possible rate and whether the small repairs that may be necessary are noted and taken care of by this department.

MR. H. T. OWENS: The illuminating engineers of the United States are the fixture salesmen; they have more to do with lighting than all the rest of the illuminating people put together. The salesmen in retail fixture stores never come to the meetings of the Society and they don't use the title, but they have more to do with lighting than the members of this Society. The paper by Mr. Spaulding and Mr. Potter tells how things could be done and not how they are done. I know of no company that has two illuminating engineers. In the eastern part of this country there is more good gas than electric lighting for the reason that the gas companies handle fixtures and sell them and the type of fixture they sell on the average furnishes better lighting than the kind of fixture that the small electrical contractor sells.

MR. W. R. MOULTON: In Baltimore it has been found advisable for the central station to not only give advice regarding illumination, but also sell and install the proper fixtures at a fair price to the consumer. By so doing it is possible to actually give better service to customers and at the same time increase the income. I do not believe there is another large central station working on this basis.

Referring to the paragraph where the authors suggest that the salesman handling a prospect be allowed to lay out the entire installation. This is no doubt advisable for simple installations, but when the problem is completed it should be referred to the department head, or someone else who is capable of giving special advice.

It is true one can often increase the energy consumption of a customer's installation and at the same time have that customer pleased. For example, he may be spending $6.00 a month for electricity or gas, and may be receiving poor illumination, poor service, poor return for his money. With proper equipment installed to give him the correct result, his energy bill or gas bill may increase to $10.00 per month, but if at the same time the service and lighting is thoroughly satisfactory, the customer will not object to the increase in operating cost.

It would certainly be inadvisable to leave the selection of the illuminant to the customer, as in few cases would he be capable of selecting what is most suitable to his conditions. By studying his present conditions and service and being familiar with results possible with the different methods of lighting, one can definitely recommend a form of lighting that would be best for the customer's special case. The gas salesmen and the electric salesmen should not be allowed to compete for his business, as they are only liable to confuse him as to the best method of lighting his establishment.

It would be well for lighting salesmen to study the results of different types of installations at night. There is a broad education to be obtained by studying and analyzing different lighting installations, both as to a judgment of the present results and a possible change that would result in improved lighting conditions, necessitating only a slight expenditure in revising the installation.

As the central station and its representatives give recommendations for lighting, why should they not also follow these with the actual sale and installation of the necessary equipment. They can then be absolutely certain that the result will be satisfactory and forestall the possibility of unsatisfactory results that often come about when the instructions are turned over to some other concern to carry out. Such a method of handling business keeps the entire responsibility just exactly where it belongs, namely with the central station, who has not only recommended, but installed the equipment to give best results.

CHAIRMAN, C. A. LITTLEFIELD: A great deal has been said this morning about education. A special man or a man holding a managerial position is highly developed, not alone in his particular field, but in the general line of his business. But it is not so much of him I wish to speak as of the man who is out on the street—the average salesman. It is not an over-easy matter to get a good salesmen; some people are naturally salesmen, they are born—not made. But it is sometimes possible to improve even this man by giving him a broader educational foundation upon which he may base his selling problems. Some people can sell anything from a domino to a dynamo. But as we study this paper by Messrs. Spaulding and Potter, we cannot help but be impressed with the fact that even these successful salesmen have

something to learn. I presume there is not a manager of a single corporation—large or small—who is not constantly striving to improve the calibre of his men, and it is this fact that is causing such a widespread interest in the general subject of the education of salesmen. We see this in the National Commercial Gas Association, the National Electric Light Association, and other associations of larger and smaller sizes that are conducting courses of education. It is really astonishing to see the results that are being achieved by these several organizations and the eager responses that are being made to the advertised courses, not only by the companies for their men, but by the men themselves, who are paying for these courses out of their own pockets, with the sole object of making themselves better and broader men. Men themselves are beginning to realize that their positions are much more secure the higher they are developed, and in the proportion as they themselves strive to improve their mental capacities do they improve their position as employees of successful corporations. I think that altogether too little has been said on this most important subject. Speaking personally, I am very glad indeed that this paper has been brought before this convention. I should like you to think this over seriously, and if you are in a managerial position yourself to put into effect the many recommendations of this excellent paper. But whether your position is that of a manager or otherwise, I trust that you will bring it to the attention of the executives of your company on your return home. Is there any further discussion?

Mr. Z. M. Hyer: I think a salesman can do better work if he has ony one commodity to sell. For myself I doubt if I could go out and conscientiously recommend gas, having sold electricity for a number of years. I could not do this unless I were employed by a gas company that was not handling electric products and I feel that the gas salesman would be in the same position: he could not conscientiously talk up electricity after having sold gas. It is natural that a man would feel a certain loyalty, have a certain feeling about the commodity that he is selling; he has to have confidence in it, and faith in it, and if he has that I do not see how he could offer another form of illumination as a substitute. I think both illuminants have their special uses, but for illuminating purposes I think electricity has

many advantages over gas and I don't feel that I could go out and recommend gas to a customer for all purposes; I could not go out and be unbiased in my judgment.

Mr. Norman Macbeth: The paper is valuable in calling attention to a serious situation existing in many territories served by combination companies. The lack of reasonably aggressive sales methods and the policy of waiting, often results in letting in the gasoline isolated plant. At the bottom of the second page there is the following statement: "It would seem that there is no good reason for a gas or electric company under one management adopting a policy which encourages only one source of supply. The duty of such a company is not to predetermine what service to sell, but to give the customer the benefit of the best advice and leave to him the decision." It is true that there are a great many factors entering into an installation with which the customer is more familiar than the representative of a utility company. Given the right information about rates, costs and load factor conditions he quickly decides whether he will have gas or electric service; there is very little opportunity for argument, provided, of course, that the information given the customer is as unbiased as it should be.

Toward the end of the paper it is stated, "It is the opinion of the writers that in order that a gas and electric company under one management may give the best lighting service, separate representatives who are specialists in the application of each lighting source should be employed." It has never appeared to me that it is necessary to have separate representatives. The extent of the information sought by the consumer is not difficult to secure, nor should it be involved as to require separate specialists. The average commercial installation to a specialist presents nothing difficult; the possibilities of the available gas and electric sources have been so thoroughly studied and their limitations are so well known that many of the installations required are simple problems. A plain presentation of the facts regarding the gas or electric service available for a particular purpose is sufficient to enable the consumer to reach a decision.

There is just one more question. How are the men paid; are they given a regular salary or do they work on a commission

basis; and also how many hours a day do they work? I have known cases where men have worked on a commission basis where they could not limit their work to the ordinary nine to five day. Their interest in the work and the necessity of seeing their customers at night required that they work until ten o'clock at night. How do you arrange the day's period and compensation? What are your working hours?

Mr. T. J. Litle, Jr.: Relative to the sale of both gas and electric units by combination companies, I would like to say that there are certain corporations in this country, such as large department stores, which are coming to believe that for their own protection no one system of illumination should be entirely depended on. They believe that for continuous illumination in their store it is advisable to have both forms of lighting. Now I am not speaking in a general way; I have in mind several instances where these great corporations operate both systems continuously, not just for an emergency to be used in case of accident, but as a continuous system, operated simultaneously. Now the combination company in serving a community has an advantage that the separate company does not have, and it seems to me that broad minded empolyees of such a company should bear that in mind. I understand and feel myself that the illuminating engineer is either in favor of electric or gas illumination, but if he is connected with a combination company he should sell both products and I don't think there should be a single large department store in this country, nor any large building, in which a great number of people assemble, in which the single system should be installed; some auxiliary system should be provided and this should provide continuous illumination. Take, for instance, the basements in the large department stores. If anything happens to the lighting system, a general panic is likely to occur and there will be a scramble for the exits and accidents are sure to happen; and I think that these stores should provide an auxiliary system just to meet such emergencies. There are local ordinances that provide for this in armories and other large buildings where a number of people are gathered and I think the lighting companies themselves should provide for the use of some auxiliary system.

Mr. Z. M. Hyer: I might give a little information that would be of interest, relative to the dual lighting in New York City. We have done away with dual lighting in large buildings to a large extent. This is due to the fact that the city authorities compelled the electric lighting companies to put in two distinct services. Our company has developed an apparatus, an automatic switch, by which it is possible to switch the current from one service to the other automatically. If the service goes off on one circuit the switch operates which immediately cuts in the other circuit. We are the only company that I know of that use a switch of this kind. I had an experience only a short time ago: the electrical contractors of New York City has an outing on Staten Island and were going to have a vaudeville entertainment in the evening. We assembled in the hall and when the first number was put on the electric lights all went out; in fact they went out all over that section of the island. They had a dual system of lighting installed in the building and the porter came along with a step ladder and matches to light the gas lamps. The first fixture he went to had four jets on it and after about 15 minutes he succeeded in getting one of them lighted; the delay was due to the fact that he had to renew all the mantles. We were an hour waiting for him to get all the gas fixtures in proper shape and by the time he did the electric lamps were in operation again, so the gas was not needed.

Mr. L. C. Porter: I would like to bring out the point that gas when used as an emergency system usually consists of a few open flame jets without any means of lighting them, unless somebody goes down in his pocket and gets a match; and then possibly the key to the fixture can not be found, which is as bad as if there were no fixture there. I do not call that a dual system at all. The dual system that is built along lines as nearly identical as possible and both controlled by the same switchboard is the only kind of a system to install. The point was brought up about glassware being developed for gas lighting that will give the same appearance as the electric lighted glassware. I think the manufacturers of mantles can get the desired color in a measure by using an amber light mantle and also I think the electric man should do his part; he should use a lamp with a very white light, possibly a gas filled tungsten lamp, and I think it could be worked

and developed so that one could not detect the difference between the sources either when lighted or unlighted.

MR. T. J. LITLE, JR.: I would like to say one more word. Some people argue that there is no necessity for a dual system as they have never had occasion to use it, but you might as well say that there is no necessity to have fire escapes on a certain building because you have never had a fire there. I think a dual system is absolutely necessary in halls and buildings where a large number of people are apt to congregate. Some of the larger corporations have insisted that the illuminating company themselves do this work and I know of several cases where an illuminating company, supplying only one system, was compelled even though they had to buy the gas, to put in the dual system. In a combination company, of course, this would not be necessary.

MR. G. B. NICHOLS: In reference to the question of dual lighting systems, I believe that this is somewhat a question of locality, depending on the class of service furnished. In first-class cities generally, where the service is of such a nature that interruptions are very seldom, if any, and particularly those cities where all of the wires are underground and where on large installations dual systems of electric feeders are extended into the building, it appears unnecessary for two classes of service. In cities, however, where the electric service is maintained by overhead lines and particularly those fed from water power plants at a considerable distance, a dual system undoubtedly would be of some advantage.

MR. F. A. VAUGHN: I can see where the independent consulting engineer has considerable advantage over some of you. I think he can look at the problem without any bias from either side. The remarks of a previous speaker remind me of a system which has been installed in two department stores in Milwaukee where it was felt decidedly necessary to have an emergency gas installation. Instead of having the additional gas units out of symmetry, the gas unit was made as nearly identical as possible with the electric unit; its apearance was almost identical, even to the extent of carrying out the chain effect. A rigid hollow chain was made, which would allow the gas to flow to the mantle. To the customer, the store appeared to be lighted by electricity—by

only one form of illumination— and in case of accident to either system there would be sufficient light available to illuminate the counters. This installation was not only to guard against accident in case of panic, but also against theft, which is a large factor at such a time. The details were carried out a little further by providing push buttons for lighting the gas; these were on the same gang as the electric push buttons and the clerks did not know which unit they were turning on, gas or electric. This made a complete continuous auxiliary system as an emergency equipment. The ordinary emergency equipment is sometimes difficult to get on in time to prevent a panic.

Mr. N. H. Potter: Mr. Macbeth mentioned the combination man versus the special man selling both kinds of energy. He brought out the only strong argument in favor of one man selling both kinds of energy, namely, gas and electricity. Naturally there is a difference of opinion regarding which is the best plan to adopt, but as stated in the paper, we think that special men are better than the combination man. A combination man is too prone to follow the lines of least resistance; he naturally thinks that he will get the installation for either gas or electricity; hence he may not advise the best installation.

Regarding the number of men employed by our company, there are four specialists on gas, and eight on electric lighting, besides fourteen solicitors who sell gas lighting units throughout residential and business sections. These men are educated to such an extent that they are competent to properly advise a customer as to the best installation for his particular requirements. Strictly speaking, they are not technical, but practical men, and they are forced to meet conditions as they find them.

In a majority of cases their work consists principally of trying to correct mistakes that were made in the layout of the original installation, regarding location of outlets, etc. They come in contact with many conditions of this character. If a customer has insufficient or improperly placed outlets in a store, the only thing to do is to extend the line, place an additional outlet or change the location of the existing outlets and then install the best fixture for his particular requirement.

Mr. Ely spoke of the men in the house lighting maintenance

department. I think this is a more important proposition in a gas company than in the electric company. We furnish the repairs and the lamps in good condition free, but charge for the material used in putting the lamp in perfect condition. This, however, is a new department and is in an experimental stage, but promises to be a very good addition to our present organization.

Mr. Owens touched on the gas company advising a good type of fixture, and installing them. I take it that he means the company would install the fixtures. We have tried to place some semi-indirect lighting in homes and stores, but the main disadvantage we have to contend with is that the customer is inclined to look at the unit itself, thereby considering the intensity of the source instead of noting the effect and the utilization of the light to a better advantage. This is due to a lack of education on the part of the general public, a condition which will take some time to entirely overcome, and accounts for the higher intensity units meeting favor.

Mr. Moulton said that the representative should consult the department head, that he should not be allowed to lay out the installation, and that he should consult the engineer. This is done in our company if the salesman is at all in doubt. The sales manager also instructs the man regarding just what are considered good installations for different cases and how to install them. Of course the longer a man is with the company the more proficient he becomes, but we cannot always have men with experience filling these positions. It is therefore necessary to employ from time to time new men, who are instructed as soon as possible. It is better that men should be competent to handle the average case instead of bringing every installation to the attention of the department head.

If the manufacturers of glassware would adopt some measures by which they could make a bowl which when illuminated by gas would give the same color as a bowl illuminated by electricity, such a scheme would be a great improvement toward perfecting the appearance of dual installations. At present there is a noticeable difference in the color of the glassware when lighted by these two agents. The glassware lighted by gas retains nearly the same color when lighted as when extinguished, while electric light imparts an orange or pink tint to the glassware.

The elimination of this condition can only be accomplished by development of glassware by manufacturers of glassware. Manufacturers of fixtures do not appear to give enough attention to the design and construction of good combination fixtures.

All the electric solicitors are on a salary. The gas solicitors are on a salary with an addition of a bonus system. Our solicitors work from 8 a.m. until 5 p.m. unless the men wish to work after hours in order to inspect lighting conditions after dark, or keep appointments after hours. All solicitors do this more or less, especially those who have a desire to get all the business possible.

LIFE TESTING OF INCANDESCENT LAMPS AT THE BUREAU OF STANDARDS.*

BY G. W. MIDDLEKAUFF, B. MULLIGAN AND J. F. SKOGLAND.

Synopsis: The method employed by the Bureau of Standards in the inspection and life testing of incandescent lamps for the federal government is outlined and a description of the power plant, the life racks, and the photometer is given. Particular attention is directed to the special equipment of the photometer. This includes a watts-per-candle computer and a recording device by which observed values of candlepower, watts, watts per candle, and actual life are recorded on a separate card for each lamp. These records are made in such a way that life at forced efficiency is corrected to life at normal without computation or reference to tables of factors. The procedure in actual measurement and testing is described with considerable detail.

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* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

INTRODUCTION.

The first edition of "Standard Specifications for the Purchase of Incandescent Electric Lamps,"[1] issued in 1907, was the result of concerted action on the part of the federal government departments, representative lamp manufacturers, the Electrical Testing Laboratories, and the Bureau of Standards. The purpose of these specifications was to establish such standard methods of initial inspection and life testing as would permit their adoption by the government and make them available to the general public; so that all purchasers of incandescent lamps, by including these specifications in contracts, might realize the benefits of their use.

Application of these specifications necessitates careful initial inspection and reliable life tests. The specified life test procedure is so exacting and the quantity of lamps to be tested on any considerable contract so large that the purchaser, unless his facilities for testing are complete, must of necessity refer, at least, the life test work to some reputable testing laboratory. It was, therefore, the natural outcome that the Bureau of Standards should be sought and recognized by departments of the government as the authority on life tests. Initial inspection is so closely related to life test procedure and its efficiency so pronounced in the effect on the results of life test that the Bureau, almost of necessity, undertook this part of the work as well.

The design of a life test installation was therefore begun early in 1908. This was developed by Messrs. E. P. Hyde, F. E. Cady, C. F. Sponsler, and H. B. Brooks, under the direction of Dr. E. B. Rosa, chief of the Electrical Division which included the photometric section. A lamp inspector was appointed in July and the plant was put into operation in October of the same year (1908). About this time Dr. Hyde and Mr. Cady left the service of the Bureau and the work has since been carried on and developed mainly by the authors of the present paper, under the direction of the chief of the electrical division.

The whole life test equipment was originally installed in the mechanical building which houses the power plant of the Bureau. In 1913 the life racks, transformers, and photometric apparatus were removed to two adjoining rooms on the third floor of the

[1] These specifications are issued by the Bureau of Standards as Circular No. 13, which has been revised from time to time and is now in the seventh edition.

new electrical building which was then nearing completion. Although some parts of the equipment are differently arranged in the new building, the general plan has remained the same as originally designed.

The introduction of new classes of lamps, however, rendered it advisable to make considerable changes in the original photometric equipment and in the details of the method of testing. These changes have been made from time to time by those who have been most intimately associated with the work. The equipment as it now stands and the present method of the Bureau's life testing procedure in all its details are, therefore, the result of a gradual development in which various persons have been of assistance.

From the beginning the magnitude of the work of inspection and life testing has been constantly increasing year by year in consequence of the natural growth of the government's purchases of incandescent lamps. Fortunately, however, the quality of the lamps supplied has, in most cases, been fairly uniform and also above the requirements of the specifications, so that full and reliable data on the lamps supplied by each manufacturer have been obtained by submitting to life test a yearly total of not over five thousand lamps which represent about one and a quarter millions of inspected lamps.

Since inspections and tests are made primarily for departments of the government, outside tests are accepted only "when special circumstances make the test of more than usual importance." A specified fee is charged for work of this kind.[2]

In the following description of apparatus and methods of life test, an attempt is made to indicate the essential features of this work and the manner in which the testing is at present actually conducted.

PURPOSES OF A LIFE TEST.

General.—A life test may be run for any one of several reasons. For example, a manufacturer who desires quick results in order to test the effect of some modified construction or change in material may choose to burn the lamps selected at a voltage

[2] Fees for Electric, Magnetic, and Photometric Testing; Bureau of Standards Circular No. 6, p. 26, 1914.

greatly in excess of that employed in normal operation thus causing the lamps to fail in a few hours. Unwarranted confidence is sometimes placed in tests of this kind for other purposes, and attempts are made to evaluate life at normal voltage from the test results, whereas no known constants for these life corrections will apply in all cases. Although relative results may be of some value, they often point to conclusions not at all in agreement with those which might be drawn from a test at a voltage corresponding more nearly to rated efficiency.

Comparative tests of greater value may be run at or near normal operating efficiency, even on a line of uncertain voltage regulation, by placing both tests side by side on the same circuit. However, the voltage applied to the lamps of each test must be such that the average efficiency of the two groups is the same, or, if differently rated and burned at one voltage, correction factors must be applied to reduce the test results of one group to their equivalent life at the efficiency of the other group. In all cases the initial (test) efficiency must be known, if test results are to be correctly interpreted. It should be emphasized that relative results only are obtained by such a test, unless the voltage regulation is that indicated in the specifications under which the lamps are tested.

In contradistinction to these rough tests are those in which actual values of life at normal efficiency are obtained for any group of lamps. This necessitates great care in initial rating and constancy of voltage at which the lamps are operated on the life test. By choosing test efficiencies within a range through which factors for life correction have been fully established, the time necessary to complete the tests may be materially shortened. Life tests at the Bureau of Standards are of this kind.

2. *Special Purposes of Bureau of Standards Tests.*—Although the chief concern of departments of the government in connection with tests under Standard Specifications is to secure reasonably prompt delivery of lamps which meet the specified requirements, a consideration almost equal in importance is the determination from the life tests of the relative standing of the various manufactures as regards quality of output. The relative quality

thus determined is referred to and given due weight in deciding upon future awards of contract.

The evaluation of a lamp life to as high a degree of accuracy as is possible in testing a large quantity of lamps has no doubt guided the manufacturers to some extent in their improvements of efficiency ratings, notably in the tungsten lamp. Consequently manufacturers and purchasers receive all available service and assistance not only from the actual test results but from conclusions drawn therefrom.

SELECTION OF LIFE TEST LAMPS.

The Standard Specifications, in accordance with which all Bureau tests of lamps for the government are made, recognize the importance of a proper selection of samples for life test. It is assumed that no lamp can accurately represent the life of a group unless it accurately represents the group in other respects. Hence great care is exercised in the selection of the samples for life test, and no sample is taken unless the lamps have first passed the prescribed initial tests.

These initial tests are made by Bureau inspectors[3] at the factory of the manufacturer, and regular factory apparatus is used. Such testing equipment as is required in the work of inspection is usually assembled in an inspection department, so that factory work is not interfered with. In the larger factories, where initial tests under specifications are made for a number of purchasers, certain operators are employed most or all of the time in the inspection department. It is their duty to render the inspectors such assistance as may be required in making initial tests. Besides one or more photometers this department contains vacuum test equipment, special sockets supplied with current for lighting up the test lamps, and, in factories manufacturing tungsten lamps, racks for seasoning or "aging" the lamps selected. This last-named equipment has been introduced as required by Standard Specifications, because of the new process of exhaust, which produces a ductile filament, not, however, stable in its electrical characteristics; so that a certain amount of burning is necessary before the current and candlepower reach values sufficiently steady for accurate measurement.

[3] One inspector is employed continuously and another is sent out to assist him when necessary.

The quantity of lamps selected for initial tests is specified as 5 per cent. of the total of a lot including only lamps of the same size, class, and voltage range, and not less than ten lamps from any one lot. The number of lamps to be included in a lot is left to the judgment of the inspector.

The lamps must conform to certain specified requirements as regards bulbs, bases, filaments, and vacuum. Lamps which pass these requirements are then run on the photometer, and in determining their acceptability, tables of allowable limits of watts and candlepower or of watts per candle, as given in the specifications, are applied. In calibrating the photometer for these tests the inspector uses standards which have been certified by the Bureau for candlepower and current. A lot of lamps is accepted if the number of defective lamps on either test is below the specified percentage of the total.

The next step is to compute from the records of the photometric test the mean values of individual groups of test lamps representing not more than 250 lamps from any one lot. The lamp nearest the mean value of each group is selected, labeled, and sent to the Bureau to represent the group on life test.

MEASUREMENT OF LIFE TEST LAMPS.

In order to facilitate the photometric measurement of the life test lamps and still secure a permanent, accurate, and as nearly as possible, automatic card record of each lamp tested, certain modifications and additions have been made to the photometer used in this work. As these features are decidely special and not found elsewhere, their construction and use are fully explained in what follows, not only that the method of measurement described later may be better understood but also that the equipment may be duplicated by anyone desiring to use it.

1. *The Life Test Photometer.*—(*a*) *General Construction.*— The general construction of the life test photometer is shown in Fig. 1. A Lummer-Brodhun contrast photometer head is mounted upon a movable carriage between the test lamp and comparison source, the distance between the last two mentioned being 250 cm. The comparison lamp, a 100-watt tungsten, is placed in a mirror-backed box fronted by a ground glass window. This window presents an approximately uniformly illuminated surface

to the photometer, so that the glass plate acts as the effective light source and is so considered. The mirrors within the box are employed to increase the illumination of the window to a practical working value, the effective area of the window being adjusted by means of a variable diaphragm or shutter,[4] this adjustment being used in calibrating the photometer. By the screening system used, stray light is so effectively excluded from the photometer screen that measurements are made in a curtained booth about 8 feet high under conditions which might be defined as approximately "semi-daylight."

The standard lamp socket may be rotated in a direction depending upon the position of a knee switch which reverses the current in the armature of the motor; so that lamps may be rapidly turned in or out of the socket and may be rotated during measurements.

Current and voltage leads are joined to the lamp rotator by means of mercury cup connectors. Storage battery current is used in all measurements and available line voltage is adjusted by means of end-cell switches.

(*b*) *Instruments and Candlepower Scales.*—Current through the standard or test lamp is read on a millivoltmeter connected across a separate shunt. Standard or test lamp voltage is read on a Brooks deflection potentiometer.[5] On this instrument the balanced portion of the e. m. f. is read from the dial which is arranged in steps of two volts. The unbalanced portion produces current in the galvanometer circuit with consequent motion of a pointer over a scale calibrated in 0.1 volt divisions through a range of 1.5 volts above and below the dial setting; so that 0.01 to 0.02 volt is the smallest readable deflection, and the precision of any setting is within these limits. In practise a null method is used and voltages corresponding to dial settings are chosen in the measurement of all test lamps. Certain modifications described later have been made in the connections of this instrument to facilitate the convenient handling of large quantities of lamps.

Several candlepower scales are mounted on a brass drum which

[4] This arrangement of the comparison lamp and of a special resistance, described later, were introduced by Ives and Woodhull, who, for a short time, were associated with this work. See Bulletin of Bureau of Standards, vol. 5, p. 555.

[5] Brooks, H. B., A New Potentiometer for the Measurement of Electromotive Force and Current; Bulletin of the Bureau of Standards, vol. 2, p. 225, 1906.

fits within the front tube of the track. The normal scale is used when the photometer receives unmodified light from both test and comparison lamps. The choice of other scales depends upon the opening of the sectored disk[6] or the transmission of the glass screen used and upon whether these auxiliaries are used on the test or on the comparison side of the photometer. In routine work these scales are used only in calibrating the photometer, because the equipment installed eliminates all reference to actual values on the scales.

(*c*) *Wiring and Special Resistances.*—As shown in Fig. 3, the test and the comparison lamps are wired in separate circuits in order to permit a wide voltage range on the former without affecting the voltage on the latter. In the comparison lamp circuit, besides the adjustable rheostat R_2, there are two special resistances designated by R_3 and R_4, respectively. The purpose of these special resistances is to maintain the comparison lamp at certain definite colors and still permit a precise calibration of the photometer in terms of the group of standards used without making tedious experimental adjustments of resistance.

With the resistance R_3 all in circuit the comparison lamp operates at the color of carbon test lamps. With a fixed amount of R_3 short-circuited by the switch SW, a color used in the measurement of tungsten lamps is obtained. When the standards are operated at the same color as the test lamps, a color match with the comparison lamp is obtained by placing a blue glass screen (the percentage transmission of which need not be known) on the comparison side of the photometer. This is done in order that the comparison lamp may be operated at a comparatively low efficiency and thus prolong its useful life. In case it is desired to run test lamps at an efficiency higher than that which would be safe for the standards, a glass screen of known transmission must be used with the comparison lamp while measuring the test lamps, but in calibrating the photometer the screen is replaced by the sectored disk so set that the percentage opening is equal to the coefficient of the screen. In this way the standards are operated at the unmodified color of the comparison lamp and the test lamps at any desired color for which a color screen of

[6] For all work on this photometer an adjustable sectored disk is used.

the proper density for color match with the comparison lamp is selected.

The potentiometer button 2, to which the galvanometer is switched in setting the comparison lamp, is connected to contact P on the slide-wire resistance R_4 which will be described presently. In the position shown it is evident that the drop from P across the portion of R_3 in circuit is measured. This drop is proportional to the current in the comparison lamp circuit, and hence by a proper choice of resistance R_3 (which is large in comparison with R_4) the exact current in the comparison lamp for carbon color is obtained. As the voltage on the standards or test lamps is set with the switch lever on button 1, a check can be kept on the current in the comparison lamp without disturbing the potentiometer setting by simply switching the lever to a button 2. Any necessary adjustment in the current is made by means of resistance R_2 to bring the galvanometer pointer back to zero.

In calibrating the photometer the adjustment of the comparison source is easily made to within 1 or 2 per cent. in candlepower by means of the adjustable shutter on the ground glass window. The final adjustment is made by moving contact P along the slide-wire resistance R_4 a distance corresponding to the desired small change in candlepower as read from a scale of candlepower differentials placed under the wire. The changes of current produced by moving P are small, so that the changes in color of the comparison lamp thus produced are entirely negligible. Ives and Woodhull[7] made use of an adjustable resistance but the null method made possible by the modified potentiometer connections and the calibrated slide-wire resistance just described was introduced later.

(*d*) *The Watts-per-Candle Computer.*—Two sets of special scales are used in connection with this photometer. One set is used in computing watts-per-candle from the observations while the other set is used in connection with a recording device. The w. p. c. computer, which operates on the principle of an ordinary slide rule, consists of an ampere scale and a w. p. c. scale both logarithmic and calculated on the same base.[8] These are placed

[7] See note 5, p. 7.

[8] The base of a common logarithmic scale is the distance from 1 to 10, 10 to 100, etc., on the scale.

parallel to the photometric axis between the photometer head and the carriage, the w. p. c. scale (showing white in Fig. 1) being attached to the carriage so as to move with it.

The design of the computer is based upon the fact that a logarithmic scale may be constructed which practically coincides with the candlepower scale over a range extending from one-half to double the candlepower reading at the middle of the scale. The base of such a logarithmic scale for a 250 cm. photometer is 71.25 cm. and the maximum differences of a scale so constructed from the true candlepower scale, the middle division of which is 20 candlepower, are only 0.08 cm. corresponding to about 0.25 per cent. in candlepower and occurring at approximately the 14 and 28 candlepower divisions. These differences, even at the points of maximum value, are entirely negligible for the purposes of this photometer and the advantages gained by employing the logarithmic scale fully offset the small errors introduced.

The two parts of the computer are logarithmic scales constructed in this manner, but the divisions are labeled amperes and w. p. c. respectively, instead of candlepower.

Now, it is evident that, with the photometer set to a given candlepower, the ampere scale may be moved horizontally to a point where for a given voltage the corresponding w. p. c. will appear under any chosen value of current (which then corresponds to the wattage), and that after this setting the correct w. p. c. value will appear under the corresponding current at all points of the scale. Now if a lamp is run at this same voltage and the photometer is moved to the point of balance the correct w. p. c. will still appear under the observed current, because the w. p. c. scale attached to the photometer carriage has been moved in its relation to the ampere scale by a distance corresponding to the change in candlepower. The ampere scale must be reset for every change of voltage but by proper grouping of lamps a large number may be run in succession at one voltage, so that these changes are infrequent during any single run.

(*e*) *The Recording Device.*—The recording device consists of a stamping magnet, a cylinder carrying a number of scales, and a car for holding the record cards. The magnet and cylinder are attached to the photometer carriage and therefore move with it.

The cylinder is mounted normal to the photometric axis and carries three lorarithmic scales running parallel to its length, one being an hour scale, the other two being w. p. c. scales for use in measuring tungsten and carbon lamps, respectively. The magnet is supported by a rod placed parallel to the cylinder, so that the pointer carried by the magnet may be set at any division on any one of the three scales, the desired scale being presented by turning the cylinder.

The car may be moved on a track parallel to the photometric axis but is held at any one of a number of nearly equally spaced points by means of a pin placed in a corresponding hole in the track. The distance between any two adjacent holes corresponds to half the distance from 100 per cent. to 80 per cent. candlepower as read from the true candlepower scale. These holes are labeled with two series of the same letters, one series being printed in red, the other in black, the letters of the red series being placed two spaces nearer the comparison lamp than the corresponding letters of the series in black. The use of these letters will be described presently.

The observations are recorded as points stamped on plain white cards approximately 12.5 cm. by 20 cm., there being one card for each lamp (see Fig. 4). These are placed in the car with their long dimension normal to the photometric axis and therefore parallel to the scales on the cylinder. Now it is evident that the short dimension of the card may be looked upon as a candlepower scale and the long dimension as an hour scale or a w. p. c. scale depending upon which of these two quantities is to be measured and recorded. The position for the card on the photometer is so chosen at the initial measurement that the candlepower record will be made sufficiently high to permit all values during the life of the lamp to fall on the card. This is regarded as the normal position of the card and is designated by the corresponding *black* letter which is then written on the card. The card is placed in this position during all but the initial measurements, the reason for this exception being given in the following section.

The two most important quantities to be recorded are the initial (test) w. p. c. and the life. The latter is defined as the number of hours required for a lamp to reduce to 80 per cent. of

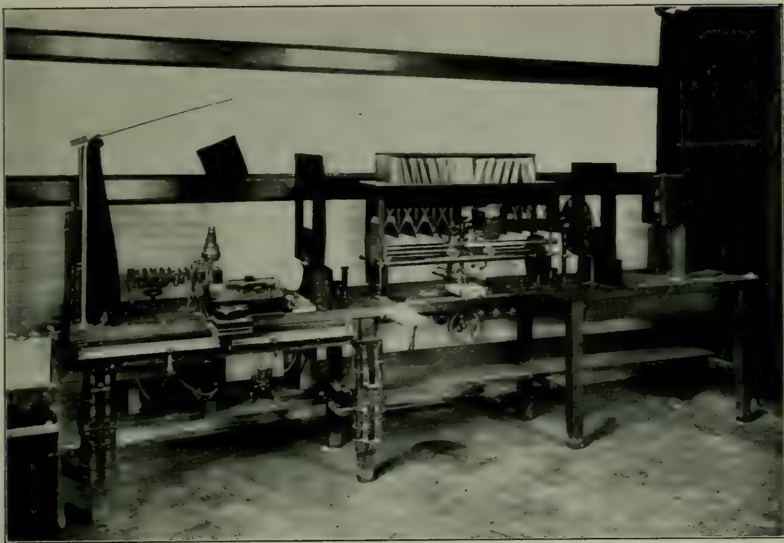

Fig. 1.—The life test photometer.

Fig. 2.—Transformers, switchboard and life racks.

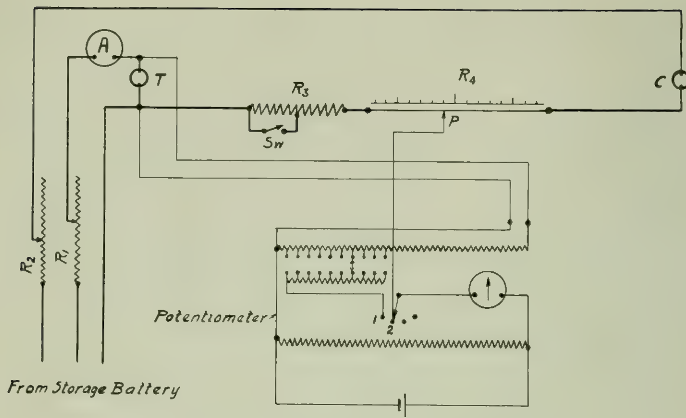

Fig. 3.—Wiring diagram of the life test photometer.

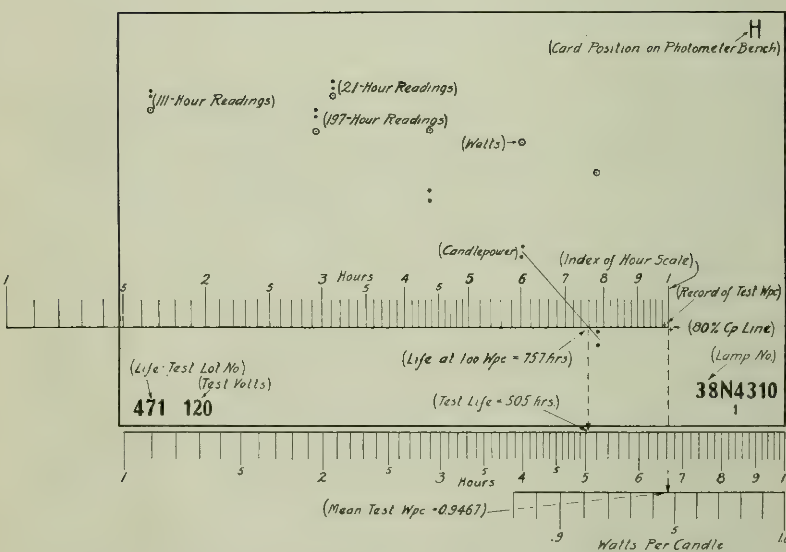

Fig. 4.—Completed test record on a lamp card showing the scales used in placing the record points and in evaluating corrected life.

its initial candlepower, or to burn out, if within that period. Now it is evident that, so far as making the record is concerned, motion of the card toward higher candlepower on the photometer is equivalent to moving the photometer in the opposite direction. If, therefore, during the initial measurement of candlepower the card be set, not at its normal (black letter) position, but at that designated by the corresponding red letter, the record point of the observed candlepower will fall at a position corresponding to 80 per cent. of the value observed. This point therefore establishes on the record the limiting line of life as defined by the specifications.

As the record of the initial measurement does not include the element of time, it may be made at any point along the 80 per cent. line. Hence, if the stamping magnet be set at the point on the w. p. c. scale (which scale for tungsten lamps is reproduced under the card in the figure) corresponding to observed initial w. p. c., not only 80 per cent. of the initial candlepower but also the initial w. p. c. as well may be recorded by the same point. To distinguish these initial points from the rest of the records, they are stamped in red (indicated by + in the figure) while all the others are stamped in black. For all but the initial measurements the card is set at the black letter position and the magnet is set at a point on the hour scale (which scale is also reproduced under the card in the figure) corresponding to the total number of hours the lamp has burned. The candlepower-hour record points are stamped in succession across the card as many times as necessary, the hour scale reading for each succeeding series being ten times the value it had in the series next preceding. The complete record thus obtained on any card graphically represents the performance of the corresponding lamp and the actual test life is indicated by the point of intersection of the curve of candlepower performance with the 80 per cent. candlepower line.

So far as obtaining a record is concerned, any scale might have been adopted for use on the cylinder in recording test life and initial w. p. c., but the scales here employed have been so chosen in respect to their relative lengths and relative position on the cylinder as to permit the evaluation of corrected life from test w. p. c. to rated w. p. c. directly from the card record without

computation or reference to tables of factors. This arrangement was based upon the following considerations.

It has been shown that within certain limits the relation between life and w. p. c. may be expressed by the formula,

$$\text{Life ratio} = (\text{w. p. c. ratio})^{m} \ldots\ldots\ldots\ldots (1)$$

in which m has been found to have a value of about 7.4 for tungsten lamps and 5.83 for carbon lamps. From equation (1) is derived

$$\log \text{life ratio} = m \log \text{w. p. c. ratio} \ldots\ldots\ldots\ldots (2)$$

analogous to the equation

$$y = mx \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

which is the equation of a straight line. Hence a logarithmic hour scale and a similarly constructed w. p. c. scale with a base equal to m times the base of the hour scale may be used together as a slide rule for making life corrections from one efficiency to another. Life in hours on the one scale is set opposite the corresponding w. p. c. on the other, and life at any other w. p. c., not exceeding the limits through which m has a constant value, is read by referring to the corresponding w. p. c. division.

The hour scale on the cylinder of the recording device was plotted to a base of 20 cm. (equal to the approximate length of the record cards) with divisions from 1 to 10, as in all slide-rule scales, and hence the base taken for the w. p. c. scale for tungsten lamps was $7.4 \times 20 = 148.0$, and for carbon lamps, $5.83 \times 20 = 116.6$.

Life requirements in the specifications are expressed in hours as rated w. p. c. As rated w. p. c. is not the same for all sizes of lamps of any class and is subject to change from year to year, it was considered best, in constructing this device, to arrange for life correction to a certain chosen w. p. c. value for each class of lamps, and by means of equation (1) compute for all sizes of the same class the required life at this chosen w. p. c. Accordingly 1.00 w. p. c. was chosen for tungsten lamps and 3.05 w. p. c. for carbon lamps. The life of any lamp, or the mean life of any group of lamps of the same size, is then expressed in per cent. of the required life.

The logarithmic hour and w. p. c. scales constructed as above described, were then so placed on the cylinder that the 1.00 w. p. c. division of the tungsten scale was in line with the 1,000-hour division of the hour scale, as shown in Fig. 4, and the 3.05 w. p. c. division of the carbon scale in line with the 450-hour division. The w. p. c. points on the card are thus recorded on a logarithmic scale and in a definite relation to the hour scale. Now if the 1,000-hour division of the scale in the case of tungsten lamps, or the 450-hour division in the case of carbon lamps, be taken as an index and a duplicate of the hour scale be placed, as shown in Fig. 4, with the proper index on the mean of the w. p. c. points of the record and with its reading edge on the 80 per cent. line, the test life, corrected to the chosen w. p. c., may be read at the intersection of the scale and the candlepower performance curve.

In case a lamp burns out above 80 per cent. of its initial candlepower value, a vertical line is drawn across the 80 per cent. line at the proper point as determined by the life test log and the hour scale, but the procedure in obtaining corrected life is the same as in the case of lamps which have burned to 80 per cent.

For lamps having other than the specified mean spherical reduction factors, the index may be so chosen that the corresponding difference is made in the corrected life. Certain special lamps, for example lamps in tubular and round bulbs, are thus evaluated.

(*f*) *Features of the Record.*—(*a*) *Detection and Compensation of Errors.*—One characteristic of these record points of the initial readings of w. p. c. and candlepower (Fig. 4) is of interest and importance in that it serves as a visual check upon the correctness of the records. Rarely do two observers on the photometer check each other exactly, but the precision of electrical instruments and the constancy of electric lamps during the relatively short time they are in circuit on the photometer are such that the ampere reading is usually repeated to within 0.001. Suppose now that at the same current the second observer reads a candlepower value higher than that recorded by the first. The w. p. c. computer will, consequently, indicate a lower value, since the candlepower is higher for the same watts. Referring to Fig. 4 it will be seen that the second point will be placed above and to

the left of the first. For a candlepower reading lower than the first, the current remaining the same, the point will be placed below and farther to the right. Supose, now, that one or other of the ampere readings is in error, the second being appreciably higher than the first. The apparent w. p. c. of the second observation is then higher than it should be, regarding the first as correct, and the effect is to change the slope of the line connecting the two observations. Displacements may occur also in case of errors in transfer to the record card or as combination of errors.

Now it is evident that the equation

$$\text{Watts} = \text{cp.} \times \text{w.p.c.} = \text{constant} \ldots\ldots\ldots\ldots (4)$$

expresses, for a steady lamp, the condition for correct reading. This is the equation of an equilateral hyperbola. Although somewhat modified by the logarithmic scale of the recording equipment, it is closely approximated in form by correctly recorded points under conditions of constant watts; so that the slope of the line connecting the initial w. p. c. points may be used as an indication of their precision, and any considerable deviation from the correct slope indicates that some error has been made. Any lamps, the records of which, show such deviations are, therefore, re-photometered.

Another interesting feature of the card record of a normal lamp is that the slope of the candlepower-life curve between its last two points is often very nearly the same as that of the line joining the two initial w. p. c. points; consequently in these cases comparatively large differences in distance between initial points effect no considerable change in corrected life, which may be evaluated with small error from any point in the line connecting the w. p. c. points. Observational errors in initial readings are therefore always compensated for to some extent by the fact that the candlepower-life and initial w. p. c. curves always slope in the same general direction. It is doubtful if any other than this system of photometry and recording posesses these advantages.

(β) *Increased Accuracy in Life Values.*—In evaluating lamps which have burned to 80 per cent. a straight line is drawn between the last two points on the record cards, one of which is above and other below the 80 per cent. candlepower line (Fig. 4). If this line be transferred to rectangular co-ordinates

it will be found that it is slightly curved, being convex downward toward the life axis. As this is characteristic of a true candlepower-life curve, this method gives, on an average, a closer approximation to the actual time of crossing the 80 per cent. line than that obtained by direct interpolation.

2. *Methods of Measuring and Recording Observed Values.*—(*a*) *Rating of Lamps for Life Test.*—Two methods are in common use in rating lamps for life test. The first distinguishes two voltages, namely, "photometer" voltage, which usually corresponds to rated voltage, and "rack" voltage. Rack voltage is computed from photometer voltage and the corresponding w.p.c. by the characteristic equation expressing the relation of volts to w. p. c. By this method the lamps are always run on the photometer, both initially and during life test, at photometer voltage. They are operated on life test at rack voltage, which of course correspond to test w. p. c. within the desired limits. By the second method the lamps are photometered and operated on life test at rack voltage. In the case of vacuum tungsten lamps, the characteristics of which are well known, either method may be used. Advocates of the first method claim advantages for it in the greater certainty of candlepower observations made at or near a color match with the standards. These are no doubt real advantages, as there is now practically no uncertainty introduced by computations based on well established values within certain limits of w. p. c. for normal lamps.

The Bureau, however, employs the second method. Although this method was adopted before the characteristics of tungsten lamps were as well known as they now are, it is still used because it introduces no uncertainties due to possible failure of any lamps to conform to the characteristic relations. Although an extra scale for reading rack voltage could easily be added to those above described, thus permitting measurements at photometer voltage, a careful investigation of the possible added advantages thus secured as weighed against a somewhat greater complexity of apparatus and consequent added liability of error would first have to be made, if a change to the first method should ever be contemplated.

(*b*) *Details of a Photometric Run.*—As a Lummer-Brodhun

photometer is used, all measurements are made at as nearly a color match as possible. By the method at present in use, the photometer is always calibrated by six tungsten standards selected at random from a much larger group. The values of candlepower and current for the individual lamps of this group, over a wide range of voltage (and color), are tabulated on a card within view of the electrical operator and in what follows these are designated as "certified" values. The comparison lamp is adjusted in current so as to give the proper color to match the lamps to be tested, this being done by simply balancing the potentiometer against the voltage drop across resistance R_3 (Fig. 3), the small adjustment necessary being made by means of resistance R_2. Switch SW is open or closed, depending upon whether carbon or tungsten lamps are to be measured. The first standard is then placed in the socket and adjusted in voltage to match the modified or unmodified color of the comparison lamp depending upon the efficiency at which the test lamps are to be measured (see p. 821).

After the color adjustment, the certified candlepower value of the standard, at the voltage to which adjustment was made, is called off by the electrical operator, and the photometer operator so adjusts the shutter on the ground glass window which fronts the comparison lamp-box that a balance is secured at approximately the certified value as read on the candlepower scale. After this approximate calibration, a stamped record of about ten individual settings is made for each of the six standards. After the observed values of a standard are recorded, the certified value is called off by the electrical operator and, with the photometer set at this point on the scale, this value also is stamped on the card. A copy of a short section of the candlepower scale is used to read off the algebraic differences between the certified and the observed candlepower values. In this manner the difference between observed and certified values of all the standards are determined and the mean difference is computed. Correction for this mean difference is then made by moving the sliding contact P of the resistance R_4 (p. 822) the proper number of scale divisions. This necessitates a small adjustment of the comparison lamp current which is now made by means of re-

sistance R_2. The electrical operator has, in the meantime, compared the observed current with the certified current and determined a mean correction for ammeter readings; or, in case lamps whose ampere readings are considerably different from that of the standards are to be run, the proper ampere standard is selected from a group of seasoned lamps used only for this purpose, and the mean ampere correction thus established is applied throughout the run. The standard check is the last direct reference made to actual values on the candlepower scale.

Having determined by trial the even voltage, (*e. g.*, 118, 120, etc.) corresponding to a dial setting on the potentiometer at which the first test lamp falls within the desired range of test w. p. c., the ampere scale is set to a point corresponding to this voltage (see p. 823). Opposite the ampere value called off by the electrical operator is read the test w. p. c. With the card so placed that the value to be recorded will be at least two-thirds of the way down the card, the index carried by the stamping magnet is set at the observed w. p. c., the circuit through the magnet is closed by pressing a button, thus making the record of the w. p. c. and also 80 per cent. of the candlepower as a single point in red. The red letter indicating the card position is noted and a card bearing this letter is selected from the file within reach and placed face down on the photometer bench, the first record card being turned over and placed upon it. As the different lamps are photometered the corresponding lamp cards and position cards are added in regular order. The same voltage is applied to each lamp in succession until one is reached which requires a change of voltage, when the ampere scale is reset to correspond to this voltage. Readings are continued at this new voltage to a point where another change of voltage is required, etc. "Information cards" designating voltage, disk opening, card position, etc. are introduced in the proper place to indicate the changes to be made in succeeding measurements.

The photometer calibration is checked by two or three standards at intervals during the run and the indicated changes of comparison lamp current are made when required (p. 822). After the first run, cards for lamps of the same voltage, disk opening, card position, etc. are grouped together to the best

advantage, the extra information cards being removed and filed for future use. The life-test lot number, the voltage, and position letter are then printed or written on each card, and the lamps rearranged for a second run in the order determined by the card positions, thus facilitating the work. After the second run, for which the two operators exchange places, such additional check measurements, as are found necessary (p. 828), are made. The lamps are then ready for the life test racks where they are burned at the respective voltages found.

After the first period of burning on the life test, the lamps are removed, placed in the proper order and again run on the photometer at the test (rack) voltages. The cards are now set to the *black* letter position (p. 824) indicated on the information cards and on each lamp card, and the stamping-magnet index is placed at the point on the hour scale corresponding to the number of hours the lamps of the lot have burned.

The ampere scale is set as in the initial run, and, after the observed candlepower value is recorded, the photometer is set so that an index on the movable part of the w. p. c. computing device is opposite the observed current value and a record of the position is stamped. As the voltage at every measurement of a given lamp is the same, this record shows the variations in the watts during the life of the lamp. (These points are surrounded by circles in Fig. 4.)

Measurements are made in this manner after each test life period until all lamps of the lot have crossed the 80 per cent. candlepower line or burned out above it.

THE LIFE TEST.

1. *Design of the Installation.*—At the time when the design of the life test equipment was under discussion, the common method in use elsewhere of setting individual lamps or racks of lamps to a desired test voltage was by means of a resistance in series with each lamp or rack. The disadvantages of this method were apparent, and search was therefore made for an arrangement of equipment which would be free from these disadvantages but which would still conform to the requirements to be met. An arrangement of auto-transformers proposed by Mr. Brooks was adopted because of its simplicity, convenience, and general conformity to the requirements of life-test operation.

Other laboratories have since adopted the essential features of this arrangement which are fully described below.

1. *Wiring and Voltage Adjustment.*—Referring to the wiring diagram, Fig. 5, which exhibits the essential features of the system, it is seen that alternating current is supplied by the generator to the center of distribution. Auto-transformers T_1 to T_4

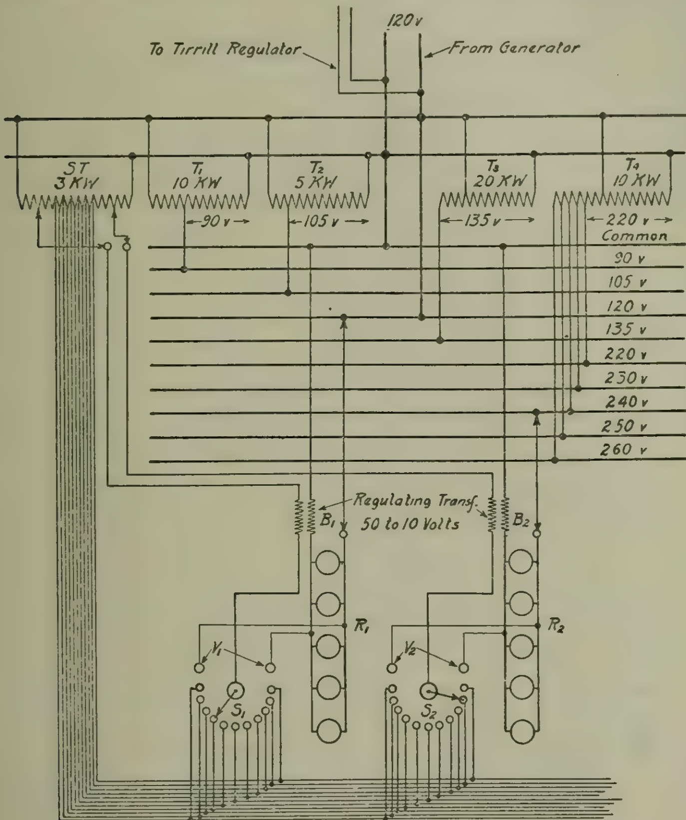

Fig. 5. Wiring diagram of the switchboard and life racks.

supply current to the bus-bars at the voltages indicated.[9] These bus-bars are mounted on the back of the switchboard panel to the right of the clock (Fig. 2). One terminal of each rack (horizontal row) is connected to the common bus through the secondary of a regulating transformer B; the other terminal is connected to a plug hole in this same panel. Hence, to energize a

[9] No provision has yet been made for low voltage or series burning lamps.

given rack R a connecting cable is plugged from the corresponding plug hole to the bus maintaining the voltage nearest to that desired. The conductors from the switchboard to the racks are of No. 4 wire carried through ten lines of 2-inch conduit running over the tops of the switchboard and racks to junction boxes from which connection is made to the terminals of the copper rod conductors of the racks.

The special auto-transformer ST maintains voltages of +5, +10, +15 to +50, and corresponding negative voltages on bus-bars located on the front of the middle panel. One primary terminal of each of the regulating transformers B ends in a corresponding plug hole also on this panel. As the ratio of transformation of the regulating transformer is 5 to 1, it follows that + or — changes of 1, 2, 3, to 10 volts may be made effective on the rack. Hence, by plugging from the transformer terminal to the proper bus-bar on this panel, a second approximation to the exact voltage desired on rack R is obtained.

The other primary terminal of each of the regulating transformers ends in the lever of a corresponding dial switch S located on the left panel of the switchboard. The buttons of each switch are maintained one volt apart over a range of 10 volts, by leads from adjacent one-volt subdivisions of transformer ST, but because of the 5 to 1 transformation in B each volt at the switch is effectively 0.2 volt on the rack. Hence, by properly setting the switch the exact voltage desired is approximated to within 0.1 volt.

The voltage of each rack is adjusted at the switchboard by reference to a portable voltmeter which may be connected to the corresponding pair of binding posts forming the terminals of the potential leads V from the center of the rack. The voltage of a rack is thus adjusted by actual measurement in every case. Each pair of binding posts appears on the corresponding dial switch. As these switches are grouped on a single panel, any number of racks may be quickly set without inconvenience with the voltmeter kept in a fixed position on its stand.

(*b*) *Voltage Regulation.*—A Tirrill regulator, which operates by periodically short-circuiting a resistance in series with the exciter field, maintains the voltage at the center of distribution

in the life test room constant to within the limits of plus or minus one quarter of 1 per cent. as required by the specifications. A continuous record of this voltage is obtained on an accurate recording voltmeter located in the dynamo room.

(*c*) *Current Generator and Voltage Transformers.*—The generator which supplies current for the life test is a 40 kw., 125-volt, 360 r. p. m., single-phase, rotating-field alternator, directly connected to the driving engine, the exciter being mounted upon the same shaft. Transformers B (shown back of the switchboard in Fig. 2) are one-half kw., air-cooled, shell-type; while ST and T_1 to T_4 are oil-immersed, auto-transformers of the capacities indicated in Fig. 5, the relative capacities of T_1 to T_4 being roughly in proportion to the number of lamps usually run at their respective voltages.

(*d*) *The Life Test Racks.*—The supporting frames of the racks are built up of steel members consisting of vertical end posts of channel section and equally spaced intermediate posts of I-beam section connected by heavy angles to horizontal top and bottom pieces of channel section, the whole being supported by cast iron feet bolted to the composition (tileine) floor. Bolted to each side of the vertical members are six equally spaced horizontal strips of asbestos board which support porcelain cleat sockets, spaced on 12 in. (30.5 cm.) centers, with soldered electrical connections to copper rods 5 mm. in diameter. Midway between each pair of these sockets, which are arranged for burning the lamps in a horizontal position, conducting straps are soldered at one end to the 5 mm. copper rods and at the other end to the terminals of porcelain cleat sockets arranged for burning lamps in a vertical position. The long racks (17 ft. (5.18 m.)) have 31 sockets on each side; the short racks (13 ft. (3.96 m.)), 23. On a few of the lower racks the sockets for vertical burning are spaced on 18-in. (45.7 cm.) centers. The large lamps burned on these racks are thus kept well separated during life test. The total number of vertical sockets is 1,200 and of horizontal sockets, 1,296.

The eight stacks of racks are spaced 4 ft. 10.5 in. (1.49 m.) apart, which gives a symmetrical arrangement in the life test

room with sufficient space to permit safe and convenient handling of lamps.

(*e*) *Measurement of Life Test Periods.*—An important detail in conducting a life test is the accurate measurement of the time the lamps have burned. For this purpose an electric clock which measures time in hours from one to one thousand is used. This clock is connected in the master clock circuit of the Bureau and is short-circuited by a relay when the power is cut off. The log of any life test contains the clock time to the nearest 0.1 hour, corresponding to the time of placing the lamps on and removing them from the rack circuit. The time of burnouts during the night is either recorded by the watchman who visits the room every two hours, or the lamps are considered as having burned until 9.00 o'clock the following morning.

2. *Records Taken During Life Test.*—Summarizing the records which are taken during life test, as described above, it will be found that the following have been mentioned:

(*a*) Test voltage; initial candlepower and initial w. p. c. at test voltage.

(*b*) Candlepower and watts at certain periods during test life. For carbon and metallized filament lamps the specifications require measurement after approximately 50 hours of burning and "at least every hundred hours thereafter" throughout useful life. Five measurements, the first approximately one-twentieth of the test life period, after the initial are specified for tungsten lamps.

(*c*) Recording voltmeter records of main life test voltage.

(*d*) Test log showing clock reading from which test life periods are computed.

In addition to the above there are, of course, required such other records as will permit orderly clerical procedure. A card record system is used throughout, but the details, which have been worked out to take care of features in some cases peculiar to the Bureau tests only, would hardly be of general interest.

SUMMARIES OF LIFE VALUES.

After the completion of a sufficient number of test lamps to warrant quality comparisons, life values of lamps of the same type, size, and manufacture, and of a voltage range through which a given life value is specified, are averaged. A summary giving

the date, type, size, manufacture, voltage range, number of lamps, corrected life and percentage of required life is prepared from these data, so that a manufacturer may, at his request, refer to the summary for information regarding the quality of his lamps and those of other manufacturers supplying lamps under the annual contract. In case lamps are rejected as the result of life test the manufacturer and purchaser are promptly notified, each being given the life value on which rejection is based.

Additions of other lamps are made to this summary from time to time, so that average quality values to the corresponding date are indicated; except, that in case of a drop in quality of certain items so decidedly below the required life that rejection of the defective lamps is necessary, the figures for accepted and rejected lamps are kept separate until the end of the tests, when the average life of accepted and rejected lamps combined is reported as a final value.

DISCUSSION.

MR. LEONARD J. LEWINSON: As one "life tester" to another, I want to express my appreciation of this paper. The authors are to be congratulated on their able exposition of the subject, on the admirable detail of the equipment at their disposal and on their system of records.

There is no mention in the paper of measurements of mean spherical candlepower. At the laboratories with which I am connected integrating spheres are an essential part of the equipment. For filaments of different conformations, total flux measurements have always been necessary, even in the days of the old carbon lamps, and now that the gas-filled lamp has come into existence, the need is strongly emphasized. We make it a practise to test all gas-filled lamps on a mean spherical basis, and find very considerable changes in the spherical reduction factor throughout life. Even in the vacuum type, we have detected such changes, though of a rather small order in the lamps as constructed at present. Some of our vacuum lamp life tests are now on a spherical candlepower basis, and we expect to be making all life tests on this basis in the course of the next year.

As the authors state, some life testing organizations measure

lamps at an arbitrary voltage, usually the labeled voltage, and calculate the rack voltage, or voltage at which they are to be burned on life test. At the Bureau of Standards, however, the actual test voltage is measured. This practise is to be endorsed. At the Electrical Testing Laboratories we use both methods, even in forced tests, employing the calculated voltage as an approximation and the actual measured voltage as the correct test value. At the Bureau, the tests are made on a 60-cycle current. At the Laboratories the majority of lamps are operated under similar conditions; in addition, at least once a year we test a substantial number of lamps on direct current. At present we are also engaged in testing several groups of carefully selected lamps at 30, 40, 60, 90, and 150-cycles.

From the statement at the foot of the fifteenth page, it appears that tungsten lamps are tested at the Bureau at about 1.0 watt per candle. Above, on the same page, the relation of life to watts per candle is expressed as a parabolic curve with an exponent of 7.4, with a qualification to the effect that the equation is limited in its use to a certain range of watts per candle. Now small tungsten lamps, 10 and 15-watts, are rated at 1.35 to 1.15 watts per candle, so that it would appear that a test at 1.0 watt per candle is in effect a considerably forced test on these small lamps. I should like to ask the authors what their experience has been in reference to the applicability of the correction factor based on the 7.4 exponent in tests on such small lamps?

MR. J. L. MINICK: The Pennsylvania Railroad is one of the few large corporations that makes a careful inspection and test of the incandescent lamps purchased for its use. It may be of interest to some of you to know that their routine method of inspection and test follows closely that established by the Bureau of Standards. Their laboratory equipment, however, is not so elaborate and probably not so accurate as that used by the Bureau, though check tests with the Bureau and other laboratories show that very accurate work is being done at the Altoona laboratory of the railroad. The remodeling of the laboratory equipment has been under consideration for some time, but prospective changes in lamp design seem to warrant postponing definite action until it can be determined whether the rating of lamps will be changed

from a "mean horizontal" to a "mean spherical" candlepower basis.

I am sorry that the authors of this paper have not touched upon this phase of their work. The introduction of the gas-filled lamp will undoubtedly make it necessary to abandon "mean horizontal" candlepower as the basis for rating lamps. This will bring about changes in routine methods of inspection and test and will probably require changes in laboratory equipment and it is essential that the Bureau of Standards, which is accepted by the manufacturers and most of the large purchasers as the arbitrator in case of dispute, be prepared to offer advice concerning the changes indicated above.

The Pennsylvania Railroad practise differs from that of the Bureau of Standards in that they depend largely upon forced or excess voltage tests to determine whether the life performance of the test samples is satisfactory or not. The excess voltage life values used are determined from the formula quoted by the authors, that having the exponent 7.4. The average test life of all lamps tested throughout a period of some four or five months checks very closely with the values determined from the formula, though many individual tests show rather wide variations.

MR. P. S. MILLAR: I should like to add a word of commendation of this paper. The authors have succeeded in presenting very clearly an excellent description of the life testing system, which is very highly developed. They have refined mechanical and electrical details in a way which I presume contributes to accuracy and economy. I believe they have an excellent system and are doing very good work.

Just a word of a general nature on this question of lamp life testing. There prevails in many quarters the notion that if a few lamps of a number of different brands are subjected to tests, the result will be an adequate guide for purchasing purposes. That is not so. You will note that this paper states that the tests are spread over a million and a quarter lamps. Mr. Minick in describing the tests of the Pennsylvania Railroad states that the purchases are on the order of a million lamps per annum. When purchasing in such quantities, lamp life tests can be made very valuable. In small purchases it is impracticable to conduct life

tests which will result in ultimate economy. It is important in any life testing of lamps to know the real cost of the work and to compare such cost with the value derived from the test in improvement of the quality of the lamp obtained for use.

There are three questions which I should like to ask the authors regarding not so much the details of life testing as the general principles of the conduct of such a test. I ask them because the same problems have come to me and I have found difficulty in meeting them. If two groups of, let us say, 6 incandescent lamps of two different brands are submitted to the Bureau of Standards for life test, I should like to ask what action the Bureau takes. Do they test the lamps? Do they qualify the report in any way when the report is rendered? Second, if two such groups of lamps are presented for tests and the lamps of one group were manufactured to be operated at one and seven hundredths watts per candle and the lamps of the other group were manufactured to be operated at one watt per candle, and the groups are of different brands, what action does the Bureau take in regard to tests and results? Are both groups operated at one watt per candle, or are they operated at the respective watts per candle for which they were intended? Third, if two such groups were presented for tests and the Bureau does not know at what watts per candle they were intended to be operated, what action is taken in the running of the test and the preparation of the report? These are very important questions and questions of a very practical nature, and I am frank to say that I hardly know what is the right answer.

Dr. C. E. Mees: With regard to Mr. Millar's point as to the testing of lamps in small establishments, I will point out that there is another side than the question of whether a saving could be made on the cost of lamps. In a good many manufacturing establishments bad lamps are not replaced as adequately as they should be when their efficiency gets down. Their replacement is sometimes difficult because of the nature of the work. It is sometimes difficult to take out lamps, as in our case, the Eastman Kodak Company, and in other cases the efficiency of the department replacing the lamp is not all it should be; so that bad lamps are a source of more cost than is apparent owing to the insuf-

ficient light leading to bad and inefficient work: in many cases I believe that a properly conducted life test on all lamps purchased would pay, even though the cost of the test was greater than the actual saving made. We only use a tenth as many lamps as the Pennslyvania Railroad, but it still pays us to test lamps on the life test.

Dr. E. B. Rosa: We do not make such tests as Mr. Millar describes and therefore do not have the difficulty that he has. Our testing is almost entirely for the government; it is only occasionally that we make other tests than for the government, and those are for very special reasons. If we should make such tests, we should guard our statements very carefully indeed, and say that the results are for the particular lamps submitted and that no conclusions should be drawn for other lamps not included. As a rule, when we have made tests for others than the government, it has been on a much larger number of lamps.

Dr. G. W. Middlekauff: In reference to the question of the measurement of mean spherical candlepower, I would say that, up to the present, measurements of this kind have not been necessary in our work. The reason for this is that, in accordance with standard specifications, all vacuum tungsten lamps are tested on the basis of mean horizontal candlepower; and, with few exceptions, all carbon lamps tested have been of the regular sizes the reduction factors for which are well established. For the few special sizes of carbon lamps tested, the reduction factors are determined and the proper corrections are made in the rating. Furthermore, there have been so few gas-filled lamps purchased by the government that the number of samples selected during inspection has been entirely too small to justify the expense of testing them. However, the indications are that within the very neat future we shall be testing gas-filled lamps also, and, when we do, it is our intention to test them on a mean spherical basis.

We have done considerable work on the determination of the life-efficiency exponent for various sizes of vacuum tungsten lamps, a certain number of which each year are tested at or near normal w. p. c., but we do not have at present sufficient data on the 10 and 15 watt sizes to draw a definite conclusion. However,

the indications are that the exponent which applies to these smaller sizes is somewhat less than 7.4.

Although it is not mentioned in the paper, our tests of tungsten lamps have been made at 0.9 to 0.95 w. p. c. and not at 1.00 w. p. c. as presumed by one of the speakers in referring to the last paragraph on page 826. The meaning which this paragraph is intended to convey is that the actual forced life values of all sizes of tungsten lamps are corrected mechanically to their equivalent at 1.00 w. p. c., and of all carbon lamps to their equivalent at 3.05 w. p. c., by using the recording and computing devices in the manner described. For example, in the record of the 40 watt tungsten lamp shown in figure 4, it is seen that the actual life was 505 hours at 0.947 w. p. c., the equivalent of which is 757 hours at 1.00 w. p. c. This lamp was rated at 1.05 w. p. c. by the manufacturer and the life specified was 1,000 hours. This is equivalent to 697 hours at 1.00 w. p. c., and hence the life of the lamp was 108.6 per cent. of the life required.

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EFFECT OF ATMOSPHERIC PRESSURE ON THE CANDLEPOWER OF VARIOUS FLAMES.*

BY E. B. ROSA, E. C. CRITTENDEN AND A. H. TAYLOR.

CONTENTS.

I. PREVIOUS INVESTIGATIONS AND PURPOSE OF THIS WORK.

It has long been known that the candlepower of flames is affected by atmospheric pressure. Quantitative observations over a wide range of pressures were made by Frankland about 1859.[1] In more recent years the matter has become of practical importance through attempts to define exactly units of luminous

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[1] *Phil. Trans.*, 151, pp. 629–653, 1861.
Proc. Royal Soc., 11, pp. 366–372, 1860–62.
Jour. Chem. Soc., 15, pp. 168–196, 1862.
Pogg. Annalen., 115, pp 296–335. 1862.

intensity based on flame standards. The development of such standards which were reliable enough to repeat values very precisely, under given conditions, and the simultaneous development of electric lamps which were independent of atmospheric conditions, made possible fairly precise determinations of the effect of pressure.

In most cases these determinations were made by measurements at the prevailing pressure, the variations obtained being only those arising from the natural changes in barometric pressure.[2]

Bunte[3] made some attempts to control artificially the pressure of the air around a Hefner flame, but did not succeed in getting satisfactory results.

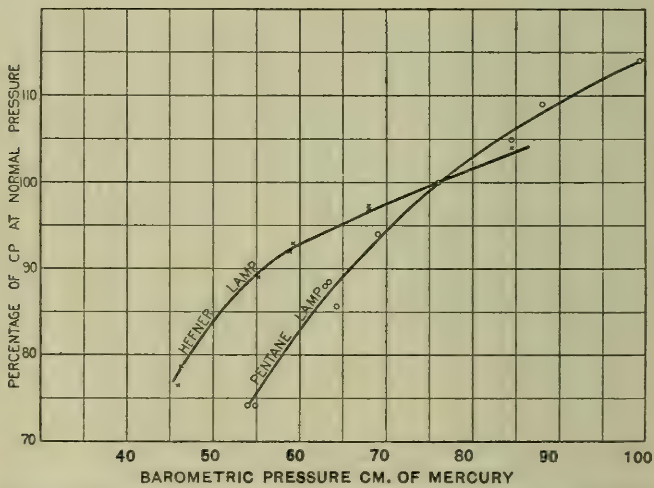

Fig. 1.—Variation of candlepower of certain flames with barometric pressure.

Butterfield, Haldane and Trotter,[4] using a steel cylinder built for the study of caisson disease, carried out the most extensive experiments of this kind which had been made up to that time. Their results on standard pentane and Hefner lamps are shown in Fig. 1.

[2] Liebenthal, E., *Zs. f. Instrument.*, 15, p. 163, 1895; *J. f. Gas, u. Wasser*,. 49, p. 561, 1906. Paterson, C. C., *Electrician* (*London*), 53, p. 751, 1904; *J. Institution of Elect. Engineering.*, 38, p. 271, 1906–07; *J. Gas Light.*, 99, p. 232, 1907: *N. P. L.*, Collected Researches, 3 p.49, 1908.

Rosa and Crittenden, Bureau of Standards Bulletin, 10, p. 562, 1914.

[3] *Jour. f. Gas u. Wasser*, p. 310. 1891,

[4] *J. Gas Lighting*, 115, p. 228, 1911.

In the United States the flame standards are not primary or fundamental, but are calibrated at the Bureau of Standards by comparison with electric standards under nearly normal atmospheric pressure. The correction for atmospheric pressure is therefore small, and although it had never been determined very accurately, the possible error (due to this uncertainty in the correction factor) in the normal value of a flame standard was very slight so long as it was used at or near sea level. When, however, such a flame standard was employed at higher altitudes, it was known that the candlepower was considerably less, but we possessed no reliable data for calculating the candlepower at such reduced pressures. It hence resulted that when flame lamps are used as candlepower standards, either for testing the candlepower of gas as given by open flame burners, or the candlepower of gas sources such as mantle burners or acetylene flames, the standard might be 10 per cent. or 20 per cent. over-rated by assuming its candlepower to be the same as it would be at normal barometric pressure, and hence the same error would be introduced into the measurements.

Nothing is more obvious than that the candlepower of a light source used as a standard should be known under the conditions of its use, and yet for lack of means of determining the effect of varying atmospheric pressure, flame standards have been used very generally at widely varying barometric pressures with values assigned under normal atmospheric pressure. Moreover, this variation in candlepower due to variations in pressure was presumably different for different kinds of lamps and burners, and yet no experiments had been made accurately enough to determine correction coefficients satisfactory even for commercial use.

Values of the pressure coefficient for pentane lamps had been computed from measurements made at varying atmospheric pressures at the Bureau of Standards, but the natural variations in the barometer at one place are too small to give reliable results by this method for pressures differing considerably. It was first proposed to select two or three test stations at different altitudes and make a considerable series of measurements on a variety of flame sources at each, and then compute the pressure coefficient from the results. Since the trouble and expense of

carrying out such a project under conditions favorable enough to give results of the required accuracy would be very great, it was decided to attempt to build an apparatus that would permit the measurements to be made in our own laboratories with variations of pressure corresponding to two or three miles range in altitude above sea level.

Our experience with flame standards had shown that for accurate measurements it is necessary to have an atmosphere free from drafts or sudden slight variations of pressure, and very perfect ventilation. At first it appeared doubtful whether we could maintain the necessary circulation of fresh air in a steel enclosure and keep the flame free from the vibrations or movements due to slight variations of pressure or drafts so as to make satisfactory measurements of candlepower. But the success of the apparatus was greater than we anticipated, and we found that flames could be burned enclosed for an indefinite period under conditions of perfect ventilation, and measurements made with less error due to variations in the flame than when they were burned as usual in the open room. The apparatus has also been used to re-determine the humidity coefficient, that is, the effect upon the candlepower of atmospheric humidity, usually expressed in terms of liters of water vapor per cubic meter of dry air.

The variation in the candlepower of a gas flame with variation of atmospheric pressure is due to two separate causes; first, the quantity of gas burned is reduced when the pressure is reduced, 5 cu. ft. per hour (for example) giving a mass of gas that is directly proportional to the pressure. Second, the luminous efficiency of the flame, that is, the quantity of light per unit mass of gas burned, varies with the pressure. The experiments give the combined effect of these separate causes, and when the first can be calculated (as when the volume of gas burned is measured) the second can be determined by itself.

II. APPARATUS.

For the purpose of controlling the pressure we designed and built a complete set of apparatus as shown in the accompanying photograph, and in the sketch, Fig. 2. Referring to the sketch, tanks A and B are each 3 ft. (0.91 m.) in diameter and 5 ft. (1.52 m.) high. Tank A has a wooden floor about 1 ft. from the

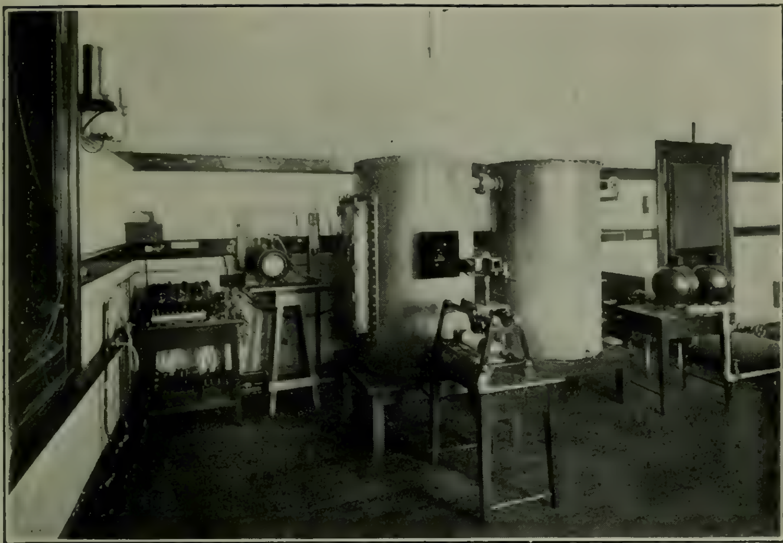

Fig. 2.—Testing apparatus.

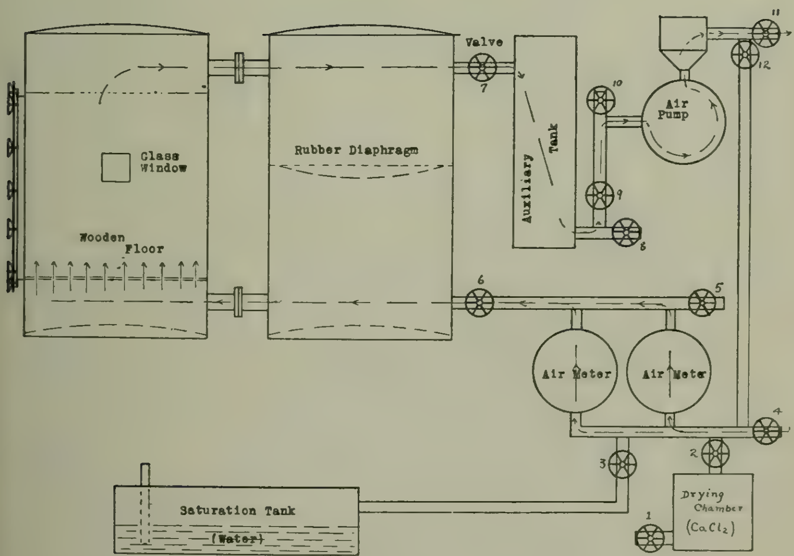

Fig. 2a.—Diagram of testing apparatus.

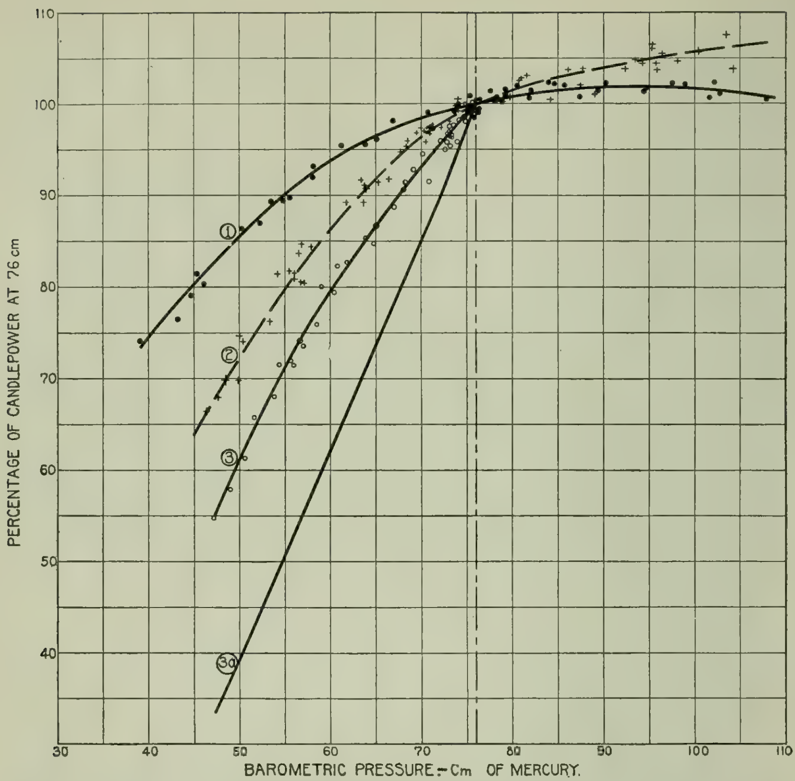

Fig. 3.—Variation of candlepower of certain flames with barometric pressure; 1—Hefner lamp; 2—Pentane lamp; 3—No. 7 Bray slit union gas burner.

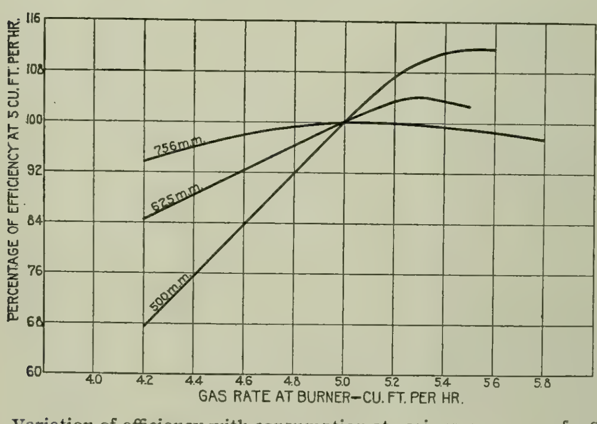

Fig. 4.—Variation of efficiency with consumption at various pressures of a Sugg's F Argand burner.

bottom. This floor has a large number of small holes, which serve to diffuse the incoming air and prevent drafts. On one side is a door 15 in. (38.10 cm.) by 30 in. (76.20 cm.) which can be made air-tight, when shut, by means of fourteen hinged bolts. Above the door a shaft enters the tank, and by means of suitable fittings it is used to adjust the flame height of the lamp under observation, there being a glass window in the door for this purpose. At a point about 90° from the center of the door is another glass window, through which the light from the lamp under test shines on the photometer screen. On the side opposite this window is arranged a cabinet containing an Assman psychrometer for measurements of humidity. This cabinet is connected at top and bottom to the tank, so that air can be drawn in at the bottom, passed over the thermometer bulbs, and back into the tank at the top of the cabinet. The fan of this psychrometer is driven by an electric motor. A mercury manometer tube is also connected to this tank to measure the atmospheric pressure in the tank. About 15 in. from the top of the tank is a wooden partition with a hole about 16 in. x 25 in. (40.64 x 63.50 cm.) for preventing the products of combustion from passing back down around the flame.

Tank B is used as an equalizing tank, to prevent sudden fluctuations or throbs of pressure. It is joined at top and bottom with tank A by 3 in. (7.62 cm.) pipes. Near the center it has a thin rubber diaphragm, to assist in eliminating pressure throbs. To the top chamber of this tank is connected another steel tank, 14 in. (10.16 cm.) in diameter and 5 ft. (1.52 m.) high, which serves as a further reservoir between the working tanks and the air pump. To the bottom chamber of tank B are connected two air meters in parallel, a calcium chloride drying chamber, and a tank containing water for saturating the air. Twelve valves are so arranged that the air may pass through the tanks in any of the following ways: Room air, through or around the meters; room air through the $CaCl_2$ drying chamber; room air through the saturating tank; room air through the pump, through the meters and tanks, back out to the room or outer air. The last named arrangement is for use in getting pressures above atmospheric pressure. The arrows indicate the path of the air when the pump is being operated as a vacuum pump, and room air is being

drawn through the meters. The pressure in the tanks and the rate of air flow are controlled by valves 6 and 7. A Zeiss refractometer, not shown in the sketch, was arranged to take samples of air from the tank for tests of CO_2.

III. MEASUREMENTS ON PENTANE AND HEFNER LAMPS.

In most of this work photometric measurements have been made against electrical standards, using the substitution method, the electrical standards being burned in place in the tank, the voltages of the standard and comparison lamps being measured by the use of a potentiometer.

When work was begun on the pentane lamp it was necessary to make preliminary tests to determine the rate of flow of air through the tanks which would be rapid enough to prevent vitiation of the air, and at the same time not to cause drafts or to affect the candlepower of the lamp by cooling certain parts of it. Rates of air flow at tank pressure from about 450 to 1,100 cu. ft. (12.74 to 31.14 $m.^3$) per hour were tried, and it was found that there was no measurable effect on the candlepower due to imperfect ventilation until the rate was reduced below 550 cu. ft. (15.57 $m.^3$) per hour. Measurements of this nature were made at various pressures, results being the same in each case. The rate finally adopted was from 700 to 800 cu. ft. (19.82 to 22.65 $m.^3$) per hour (at tank pressure). The refractometer indicated that there was no increase of CO_2 in samples of air, taken from near the flame, over that in the outside air.

Each candlepower observation at any pressure was the average of about 75 or more separate settings of the photometer. After changing the air pressure in the tanks and adjusting the rate of air flow, no measurements were made until the pressure had become constant. Candlepower measurements on the pentane lamp were made at pressures from 463 to 1,072 mm. The results are plotted in Fig. 3. The average candlepower of the lamp under normal conditions, as determined by previous measurements in the open air, was 9.78. The curve drawn to represent the average of observations at various pressures indicated a value of 9.76 candles at normal pressure and water vapor. Hence it is evident that the unusual conditions of burning did not affect its candle-

power at normal pressure. Also, the barometric pressure factor over the range from 730 to 770 mm., the range obtainable under natural conditions in this laboratory, was found to be in close agreement with that which we had obtained when burning the

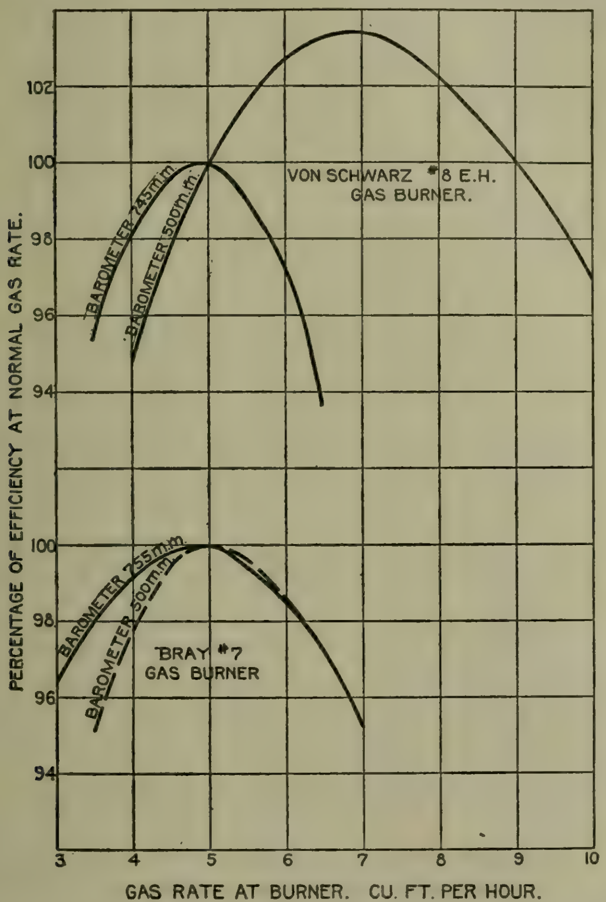

Fig. 5.—Variation of efficiency with consumption at various pressures.

lamps in open air in the laboratory, namely, 0.6 per cent. change in candlepower for 1 cm. change in pressure.

The method of testing the Hefner lamp under various pressures was similar to the above, except that it was not necessary to regulate the rate of air flow so closely. In this case the deter-

mining factor was the maximum allowable rate which would not disturb the steadiness of the flame. It is interesting to note that the Hefner flame was much steadier when burning in the tank than when burning in the open air, and the variations from the mean value at any pressure were very small, as will be seen by reference to Fig. 3. This suggests the desirability of using the Hefner in such a ventilated enclosure when the highest accuracy is desired.

For both the pentane and the Hefner lamps frequent measurements of water vapor content of the air were made, and observed results were corrected to a standard value of 8 liters of water vapor per cubic meter of dry air for the pentane lamp, and 8.8 liters for the Hefner.

IV. OBSERVATIONS ON GAS FLAMES.

In order to reduce measurements on gas flames to a definite basis, it was first necessary to determine the relative efficiency of each burner at various rates of gas flow, since it is not always possible to make the rate exactly 5 cu. ft. (0.14 $m.^3$) per hour. Such measurements were made at various pressures, and curves plotted to show the efficiency at any consumption in terms of the efficiency at a rate of 5 cu. ft. per hour (see Figs. 4 and 5), and all later observations were reduced to the value which would have been obtained if the rate had been made exactly 5 cu. ft. per hour at the pressure and temperature prevailing in the tank.

The three burners tested were the Bray No. 7 Slit Union, the Von Schwarz No. 8 E. H., and the new Sugg's F Argand. The Bray burner had its maximum efficiency near 5 cu. ft. per hour at all pressures, but the rate for maximum efficiency for the other two burners increased as the air pressure was lowered. In the case of the argand burner, especially, the corrections made by the use of these curves were very important. For example, at 500 mm. pressure a variation of 1 per cent. in rate of flow of the gas would make 2 per cent. change in the efficiency, and therefore 3 per cent. change in the observed candlepower; in other words, the indirect effect in changing the efficiency was twice as great as the direct effect of having more gas to burn.

As no gas storage tanks were available, it was necessary to make the observations in such manner as would eliminate any

errors due to change of quality of gas during measurement. The method employed was to make observations at pressures which were decreased by steps to the lowest value desired, then increased by steps intermediate between the former pressures The quality of gas usually was sufficiently constant to give very good agreement between the two series of points thus obtained.

All measurements to determine the effect of barometric pressure on the candlepower of gas flames were made with the gas rate at the burner as near 5 cu. ft. per hour as could be obtained without taking excessive care, as this is the customary test condition. Photometric and gas rate measurements were made simultaneously. The rate of air flow through the tanks was maintained at approximately 700 to 800 cu. ft. per hour. Each point plotted on the curves shown is usually the mean of 75 to 150 separate settings of the photometer, the larger number of readings being taken when the candlepower seemed to be unsteady. All photometer readings were printed on a sheet by apparatus of the kind regularly used at the bureau for this purpose, so that a great many readings could be taken in a short time, with a minimum of prejudice.

V. COMPUTING AND COMBINING OBSERVATIONS ON GAS.

In each run the observed value was corrected for the variation of efficiency with consumption, if the gas rate was not exactly 5 cu. ft. per hour. This value was further reduced to constant mass of gas, *viz.*, 5 cu. ft. at 30 in. (76.20 cm.) and 60° F. Next these final corrected candlepower values were plotted against barometric pressures, and the curve which would best represent the points obtained in that one run was drawn. As it is not possible to combine runs from day to day on a candlepower basis, because of slight changes of quality of gas from day to day, a certain barometric pressure, well within the range of pressures used, was chosen as a combination point for the various runs. For one burner tested the pressure chosen was 650 mm. After each run had been plotted and the curve drawn, the candlepower value at 650 mm. was read off from this curve. This candlepower was then rated as 100 per cent., and all observed candlepowers of this run were reduced to percentages of this value.

Each run having been worked up in this manner, all were on a common basis, and could be combined in a single plot. When this had been done, and the most probable curve drawn, all observations were then reduced to a basis of 100 per cent. at 760 mm. The observations, reduced as described above, are plotted in Fig. 6 and in order to facilitate comparison one of these curves (No. 3, that for the Bray burner) is also plotted with the pentane and Hefner lamp data in Fig. 3.

It is to be noted, however, that the standard lamps are operated at constant flame height, whereas the measurements on the gas

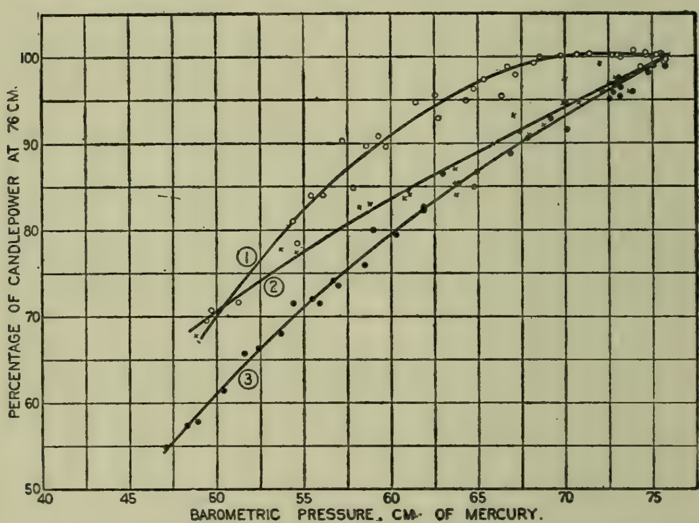

Fig. 6.—Variation of candlepower of gas with barometric pressure—constant mass of gas. 1—Sugg F Argand burner; 2—Von Schwarz No. 8 E. H. burner; 3—No. 7 Bray burner.

burners are reduced to the basis of constant (mass) consumption. These are the conditions under which the "candlepower" is calculated in gas tests, and are therefore of most practical importance; but a better comparison of the underlying phenomena is obtained by plotting, instead of the candlepower for constant consumption by *mass*, the actually measured values, which are for constant consumption by *volume*. This gives curve 3*a*, showing a still more rapid decrease in candlepower with decrease in pressure. Of course a part of this decrease is due to the reduction in the mass of gas burned, and for quantitative compari-

son with the standard lamp curves we should have either the latter corrected to constant fuel consumption or the gas curves corrected to constant flame size, which would give a curve lying between 3 and 3*a*. The point to be noted is that the open gas flames fall off in candlepower much more rapidly than the pentane lamp, which in turn decreases more rapidly than the Hefner with falling pressure.

VI. EXPLANATION OF EFFECT OF PRESSURE CHANGES.

The reason for the markedly different effects on different flames is easily found. The light of the flame supposedly comes from glowing particles of carbon set free in the earlier stages of the process of combustion. In the later stages the carbon is oxidized and becomes non-luminous. The amount of light produced therefore depends on two factors; first, the number of particles of glowing carbon in existence at one time, and second, the average temperature of these particles.

The number of glowing particles depends among other things upon the average interval between the first and the second stages of combustion; in other words, on the interval between the time when the carbon is set free and the time when sufficient oxygen is supplied to combine with the carbon. In the case of the Bunsen flame, in which the fuel and the air are already intimately mixed, this interval is practically non-existent; the carbon is oxidized before it becomes incandescent and the flame is therefore non-luminous. At the other extreme is the smoky flame in which the second stage is never completed, so that some of the carbon escapes unoxidized. The various types and conditions of luminous flames come in the intermediate region.

Barometric pressure affects the amount of light produced because it affects the rate of diffusion of oxygen through the burning fuel. In general, as the pressure grows less, the diffusion is more rapid and the "life" of the glowing carbon particles is reduced. This reduction is, however, partially compensated by the second factor mentioned, that is, the temperature of the particles, for the more rapid access of oxygen results in more vigorous combustion with a resulting higher temperature, which in turn causes each particle to emit more light while it does glow.

If, then, we start with a smoky flame (which has an excess of carbon) and reduce the pressure, an actual increase in light may result. This condition was, in fact, reached in the case of the Hefner lamp (Fig. 3), although the difficulty of setting the flame height under this condition is such that not many measurements were made in this region.

As the pressure is reduced, however, a point is soon reached where the reduction in the number of particles over-balances the increase in the light emitted by the individual particle, and from this point on the reduction in candlepower is more and more rapid.

It may be assumed that the curve as given for the Hefner lamp is typical of flames in general, but that our limitations with regard to pressure are such that for the other flames we get only small sections of the curve lying far from the maximum, which is near the pressure that would give a smoky flame. In a general way, the whiter a flame is the farther it is from the smoking point, and the more rapidly its candlepower changes with change of pressure. A few measurements on an acetylene burner, for example, indicated that at a pressure of 20 in. (50.80 cm.) its candlepower was about 52 per cent. of normal, while the various burners with illuminating gas gave 63 to 72 per cent., the pentane lamp 73 per cent. and the Hefner lamp 86 per cent., this being the order of the lamps with reference to color also. Even the difference between the effects on the two types of open flame burner might have been predicted. The Von Schwarz burner showed a decidedly higher efficiency than the Bray, indicating that its flame was nearer the smoking point, and as would be expected from this the effect of pressure changes is less on this burner.

It may appear that the curve of the argand burner (Fig. 6) is decidedly different in shape from those of the open flames, but this burner has a chimney, which so modifies the conditions with respect to mixing of air and gas that no comparison can be made with the other burners.

In this connection, however, the curves of Fig. 4, showing the variation of efficiency with consumption at various pressures, are of interest. As the pressure is lowered the consumption for

maximum efficiency is increased, just as it would be by using a gas requiring less air for its combustion.[5]

It appears, therefore, that in this type of burner also the effect of decreased pressure is attributable to a more rapid mixing of the air through the gas. The chimney, however, has the effect of making the burner pass from the condition of good aeration to that of the smoking flame within a relatively small range of pressure. So we find that at normal pressures, with the gas used in determining this curve, this burner has already passed the maximum efficiency (it was in fact on the verge of smoking), while at the other end of the pressure range it is falling more rapidly than the open flame. In other words a given range of pressure gives a larger part of the typical pressure-candlepower curve for this burner than it does for the open flames.

VII. EFFECT OF WATER VAPOR.

By means of the apparatus described on page 4, it was possible to vary the water vapor in the air supplied to the tanks over a range of 15 to 20 liters per cubic meter of air. By making observations on gas under various weather conditions, a total range of about 6 to 45 liters was obtained. Similar measurements over a smaller range were made on an acetylene flame and an Elliott kerosene lamp. All of these measurements were made at a barometric pressure of 710 mm. The observed points have been plotted in Fig. 7 in which the curve for the pentane lamp is also shown for comparison. This curve was determined by a series of measurements extending over several months, under natural conditions, and was reported on in previous papers.[6] Its accuracy was further verified by measurements in the tanks. An explanation of the method by which separate observations of water vapor effect on gas were combined is necessary, since the whole range was not obtainable at any one time. The measurements were made in three series of runs, with ranges of 24.7 to 45, 12.7 to 38.2, and 6.4 to 23.1 liters. The runs of each series were combined in a manner similar to that described above for the barometric curves. The combination points for

[5] Gilpin F. H., (*Proc. Amer. Gas Inst.*, 9, pp. 379-401, 1914.) gives a similar family of curves in which the variable condition is the richness of the gas, instead of barometric pressure.

[6] *Trans. Ill. Eng. Soc.*, 5, pp. 753-778, 1910; and 6, pp. 417-32, 1911.
Bureau of Standards Bulletin., 10, pp. 391-417, 1913.

runs of each series were 37, 22 and 15 liters respectively, the values at these points being called 100 per cent. for each series. The curve representing each series was, to all appearances, a straight line, and the straight line representing each series was computed by the method of least squares. As the slopes of the three lines were not equal, and as it was necessary to combine these three series on a basis of 100 per cent. candlepower at 8 liters, certain arbitrary points of combination were chosen. The three series had been taken with such ranges of water vapor that

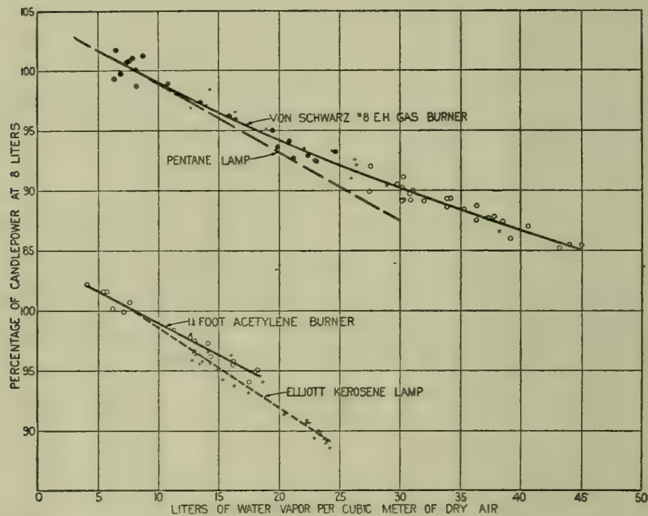

Fig. 7.—Variation of certain flames with atmospheric moisture—barometric pressure, 71 cm.

two adjacent series would overlap, and the combination point in each case was chosen near the middle of the overlapping section. These points were 18 and 30 liters. The percentages of the three series at the various points were as follows:

Series	Per cent. at 8 l.	Per cent. at 18 l	Per cent. at 30 l
6.4 to 23.1 liters..............	103.5	98.4	
12.7 to 38.2 liters	—	101.4	96.2
24.7 to 45 liters	—	—	102.8

Hence the percentage values of the first series (basis of 100 per cent. at 15 liters) were multiplied by $\frac{100}{103.5}$, and the other two

by $\frac{100}{103.5} \times \frac{98.4}{101.4}$ and by $\frac{100}{103.5} \times \frac{98.4}{101.4} \times \frac{96.2}{102.8}$, respectively. The observations then being on a common basis, they were plotted and the most probable curve drawn. The points included in the three groups are distinguished by dots, crosses and circles, respectively.

The fact that the three groups covering different ranges had different slopes shows that the decrease due to humidity is not really linear. The group of points taken at the lowest humidity gave a slope indicating a decrease of 5.0 per cent. from the normal candlepower for each per cent. by volume of water vapor in the air, whereas the pentane lamp decreases 5.7 per cent. Gilpin[7] found 6.0 per cent. for an open flame gas burner.

VIII. EFFECT OF VITIATION OF THE AIR.

It was expected that some difficulty would be met in securing satisfactory ventilation in the tanks, and hence a few preliminary measurements on the effect of vitiation of the air were made. These were not carried out fully, because it developed that the air in the tank could be kept as pure as that in the regular photometer room, so that no corrections on this account were necessary.

The measurements which were made were obtained by closing up as tightly as possible a small room in which a pentane lamp and several gas burners were kept burning. Frequent measurements of the candlepower of the pentane lamp were made, while air from the neighborhood of the lamp was drawn through the refractometer mentioned above and readings of the latter were taken at short intervals. These readings (translated into percentages of carbon dioxide in the air) and the candlepower of the lamp were both plotted against the time, smooth curves being drawn to represent the march of the two quantities. Four such runs were made and the combined results are shown in Fig. 8. The points plotted in Fig. 8 were read from the curves described, and consequently the deviations of these points indicate the degree of agreement between different runs, and not the precision of separate candlepower and carbon dioxide measurements.

The curve shows that the degree of vitiation represented by an increase of 0.1 per cent. in the carbon dioxide content of the

[7] *Loco citato.*

air caused a reduction of 3.4 per cent. in the candlepower of the lamp. As has been pointed out in a previous paper the percentage of carbon dioxide is not a precise index of the vitiation, since the important factor is the reduction of the amount of oxygen in the air, and the relation between this reduction and the increase in carbon dioxide depends on the proportions of carbon, hydrogen and oxygen in the fuel consumed. The present data therefore give only an indication of the general magnitude of the effect of poor ventilation. They are significant, however, in their relation to the use of flames as primary or fundamental standards, which involves the derivation of values for electric standards

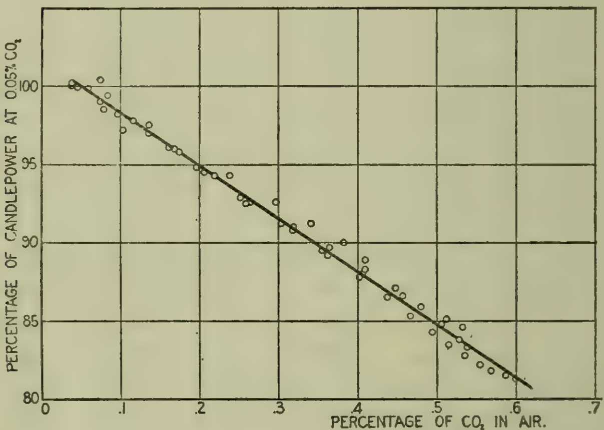

Fig. 8.—Effect of vitiation of air on candlepower of pentane lamps.

from the flames. Outdoor air contains about 0.03 per cent. of carbon dioxide, while in a well-ventilated laboratory this is likely to run up to 0.06 per cent. This is a small change for most purposes, but it corresponds to a change of 1 per cent. in candlepower. If therefore we were to attempt to derive from the flame our fundamental unit, which should be certain to one tenth of 1 per cent., far more elaborate precautions than have ever been taken with respect to control of the composition of the air would be necessary in order to avoid uncertainties due to this cause.

IX. BEARING OF RESULTS ON TESTS OF GAS.

It is of course realized that the results of such measurements as these depend to a considerable extent on the composition of

the gas. The gas used was a mixture of approximately 30 per cent. of coal gas and 70 per cent. of water gas, having an open-flame candlepower under normal conditions of 20 to 23, and an average heating value in the neighborhood of 630 B. t. u. per

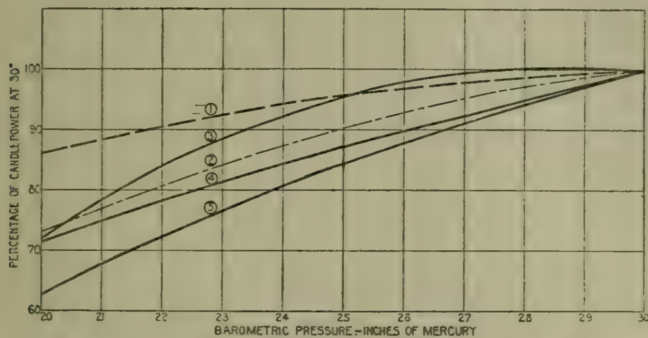

Fig. 9.—Variation of candlepower of certain flames with barometric pressure: 1—Hefner lamp; 2—pentane lamp; 3—Sugg F. Argand gas burner; 4—Von Schwarz No. 8 E. H. gas burner; 5—No. 7 Bray gas burner.

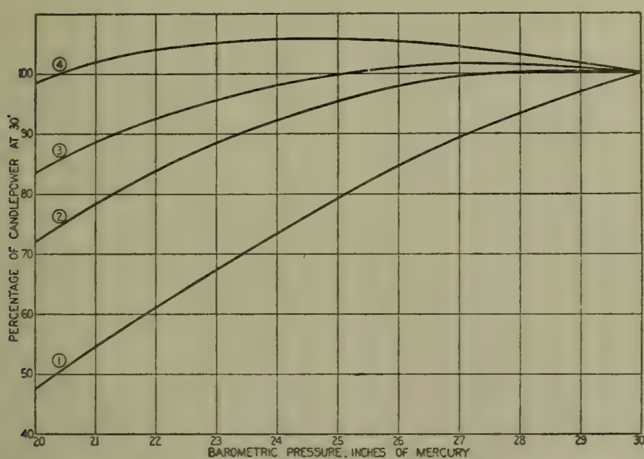

Fig. 10.—Variation of candlepower of gas with barometric pressure, Sugg Argand burner. (For significance of curves see following page.)

cubic foot. The curves given are intended to show the general nature and approximate magnitude of the effects and are not to be considered a basis for exact corrections to be applied in other cases.

Nevertheless the results are sufficiently significant so that it

has appeared worth while to plot various combinations of the data in such a way as to emphasize their bearing on tests of gas. Since the data of such tests are commonly expressed in English units these curves have been plotted with barometric pressures in inches.

In Fig. 9 are collected the curves already given for the two flame standards and for the three types of test burners, the values plotted for the latter being as before corrected to a rate of 5 standard cu. ft. per hour. The significant point in these curves is the variation in the ratio of gas flames to standard lamp.

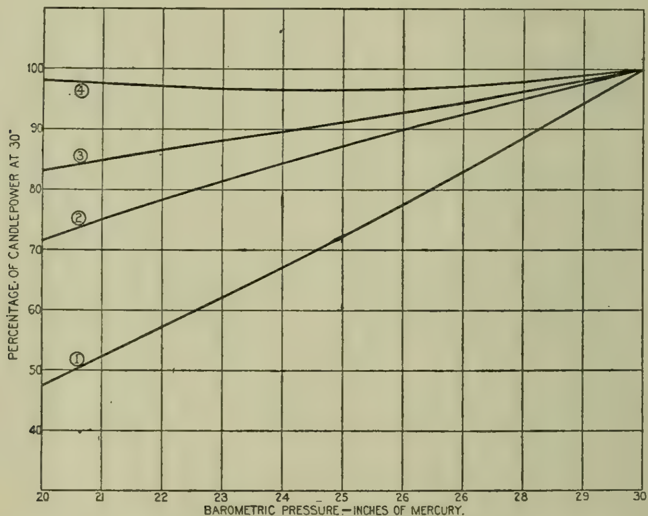

Fig. 11.—Variation of candlepower of gas with barometric pressure, Von Schwarz No. 8 E. H. burner.

In order to bring out more clearly the effect of this variation we have plotted in Figs. 10, 11, and 12 four curves for each type of burner. In each case curve No. 1 shows the actual candlepower of the gas flames (as measured by an unvarying standard such as an electric lamp) burning a constant *volume* of gas per hour, that is, 5 cu. ft. per hour at 60° and prevailing pressure. Curve No. 2 shows the candlepower corrected to a constant *mass* per hour, that is, 5 cu. ft. at 60° and 30 in. pressure. Curves 3 and 4 in each case show the apparent candlepower which would be obtained if instead of an unvarying standard a Hefner lamp

or a pentane lamp were used for the measurements without making any correction for its departure from normal value, the gas rate being corrected in the usual way to 5 standard cubic feet per hour.

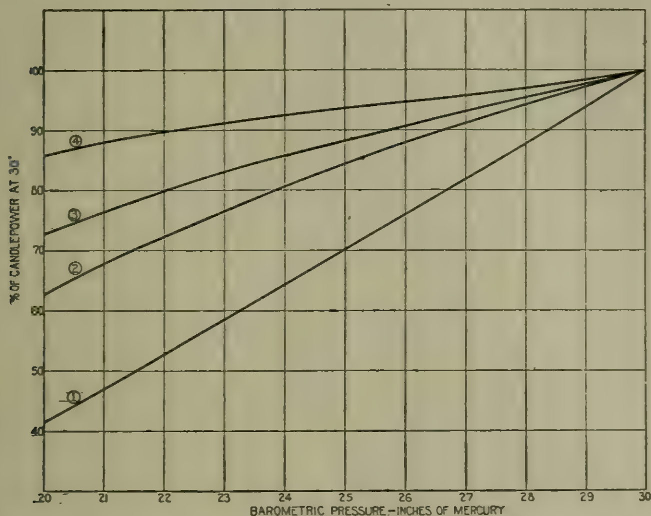

Fig. 12.—Variation of candlepower of gas with barometric pressure, No. 7 Bray burner.

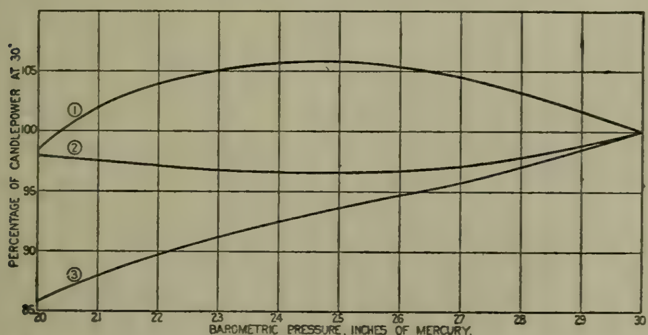

Fig. 13—Effect of barometric pressure on "candlepower" of gas as measured with pentane lamp. 1—Sugg F (Argand); 2—Von Schwarz No. 8 E. H. burner; 3—No. 7 Bray burner.

Since the pentane lamp is generally accepted in the United States as the most suitable standard for gas tests the rated candlepowers which would be obtained by using it and correcting gas

volumes in the customary way are of special interest. Consequently the curves for the different burners showing the results which would be obtained by tests made with the pentane lamp as a standard are collected in Fig. 13.

The significance of these curves will perhaps be made more clear by considering a definite example. Suppose the candlepower of a given gas, burning at 5 cu. ft. per hour at sea level (30 in. barometric pressure) in a Bray No. 7 slit union burner is 20.0. If the same gas is burned in the same burner at 5 cu. ft. per hour at 25 in. pressure, we might expect the candlepower to be $^5/_6$ as great, that is, 16.7, since about $^5/_6$ as much gas is contained in the 5 cu. ft. But actually the candlepower is found to be only 14.0, that is, 70 per cent. of 20, as shown in Fig. 12. On the other hand, a "10-candle" pentane lamp at 25 in. pressure gives only a little over 9.0 candles. Consequently if we call it 10 candles, the apparent candlepower of the gas flame will be 15.5, and the customary correction to allow for the fact that only $^5/_6$ of 5 standard cu. ft. of gas are burned gives a rated candlepower of 18.6. More exact calculations have been plotted in the curves, and from curve 3 of Fig. 12 we see that at 25 in. (63.50 cm.) pressure the Bray burner gave 93.5 per cent. of normal values, or 18.7 candles when the normal was 20.

On the other hand if one had used the Sugg Argand burner the rated candlepower would have been nearly 6 per cent. above the normal value, while with the Von Schwarz burner it would have been 3.5 per cent. below the normal; the actual candlepower, however, being 15.9 and 14.5 respectively, for gas whose normal rating would be 20 candles.

It should be noted that by "normal" for each burner is meant the sea-level value which would be obtained with that particular type of burner, and similarly the 100 per cent. point on all the curves is the sea-level value for the particular burner to which the curve applies. With the gas used in these experiments the Argand burner gave the highest candlepower, the Von Schwarz and Bray burners being respectively 2 and 7 per cent. lower. That is, the same gas gave 20 candles in the Von Schwarz burner, 20.4 in the argand and 19.0 in the Bray. Different burners of the two open-flame types selected at random were found

to give remarkably uniform results, being in this respect decidedly superior to argands.

X. TYPICAL APPLICATIONS TO GAS MEASUREMENTS.

From reports of the Weather Bureau, average values of water vapor and barometric pressure for five years, from 1904 to 1908 inclusive, for eleven widely separated cities have been obtained. It is customary to rate a pentane lamp at the candlepower it would give under normal conditions of 8 liters of water vapor per cubic meter of dry air and a barometric pressure of 760 millimeters of mercury. If its candlepower under these conditions were 10.0, the following table, column 3, would show its average candlepower for the five years in each of the eleven cities. Assuming a mixed gas of a composition like that tested here, giving a candlepower of 20 when burned in a Von Schwarz No. 8 E. H. burner under normal conditions of 8 liters and 30 in. pressure, the rate being corrected to 5 cu. ft. per hour at 30 in. and 60° F., its actual average candlepower in the various cities is shown in column 6. Column 7 shows the average values which would have been obtained if measurements had been made in terms of a pentane lamp rated as explained above. Column 5 shows the average candlepower which the consumer would have obtained for a meter rate of 5 cu. ft. per hour at 60° F.

TABLE I.—CALCULATED RATING OF GAS AT DIFFERENT PLACES.

Gas assumed to give 20 candles under normal conditions; all tests supposed to be made with pentane lamp and Von Schwarz No. 8 E. H. Burner.

City	Average barometric pressure	Av. water vapor (liters per cubic meter)	Av. cp. of pentane lamp	Av. actual cp. of gas, at rate of 5 cu. ft. per hour at 60° F.	Average cp. of gas corrected to 5 cu. ft. per hr. at 30 in. and 60°	Av. cp. of gas as rated with pentane lamp
Atlanta	28.84	14.3	9.49	18.3	18.8	19.8
Boston	29.88	9.9	9.88	19.9	19.8	20.0
Cheyenne	24.01	7.3	8.77	13.8	16.9	19.3
Chicago	29.15	10.6	9.75	18.9	19.3	19.8
Denver	24.73	7.9	8.95	14.4	17.3	19.3
El Paso	26.19	9.2	9.27	15.8	18.0	19.4
Helena	25.80	6.8	9.30	15.6	18.0	19.3
New Orleans	30.00	19.1	9.37	19.1	18.9	20.2
San Francisco	29.87	11.3	9.79	19.7	19.6	20.0
Sioux City, Iowa	28.80	9.2	9.78	18.7	19.3	19.7
Washington, D. C.	29.94	12.0	9.77	19.7	19.6	20.0

If a different burner were used the departure from normal candlepowers would be different. For example, in the case of Denver, the Sugg F Argand would give for the last three columns 15.6, 18.9 and 21.2 (assuming a gas which under standard conditions would give 20 candles in that burner).

From an inspection of the last column in the above table, it is readily seen that the candlepower obtained in tests by correcting results in the ordinary way does not necessarily indicate the quality of the gas supplied closely enough for a comparison of gas plant output in different cities. It is still further from an indication of the average service which the customer is receiving. If the latter is the purpose of tests of gas candlepower, it would seem to be a more rational procedure to use a value for the standard lamp which represents its actual candlepower under the atmospheric conditions where and when it is in use. Also, instead of correcting the volume of gas to its volume at sea level, it would be better to correct it to the volume at average atmospheric pressure in the city where tested. Candlepower tests would then indicate the service rendered much more closely than at present. The average conditions for any city can be determined quite closely from the reports of the Weather Bureau.

DISCUSSION.

MR. F. H. GILPIN: I think it is well to emphasize the fact of the type of gas on which these experiments were made. If one takes a burner like the Sugg "F" Argand and burn it, first, on a water gas and then on a coal gas, totally different results will be obtained. That particular burner is probably designed for a little higher consumption than five feet. Atmospheric humidity will materially affect the efficiency of these burners, depending on the kind of gas burned in them. In burning a coal gas, a higher percentage of error will be obtained as the humidity increases, than with the water gas. Another point in the measurement of the gas in those tests is this; ordinarily, in measuring candlepower, the gas is measured by constant volume and corrected to constant mass. I am interested to know if any different results would have been obtained in the curves

if that had been ordinarily done in the test? I notice in the photograph that the meter was located outside the tank.

Mr. F. E. Cady: It seemed rather interesting to me to notice that this effect of increasing pressure on the flame candlepower was in the same direction as that found by Lummer in his measurement of the effect of pressure on impregnated carbon arc lamps, and I wondered whether the authors think that the explanation given of the effect in this case would be similar and would apply to the effect obtained on the arc lamp.

Dr. E. B. Rosa: I might call attention to one practical effect of this result: heretofore the Bureau of Standards has always certified pentane lamps for what we call their normal candlepower, and that has been used as their actual candlepower in all altitudes. Even in places no higher above the sea than Chicago, there is an appreciable difference between the candlepower and the candlpower at sea level, and of course there are many cities of considerable size in this country where the altitude is several thousand feet and the barometric pressure effect is correspondingly great. We have never been able to give with a certificate of the pentane lamp, a certificate of what its candlepower would be at the place where it was destined to be used, for the lack of the information now available. We expect hereafter to give such statements, so that the actual candlepower will be known, and that will have a very decided effect on the value obtained by the use of the lamp, if the actual candlepower at a given place is used instead of its candlepower at sea level pressure. We have purchased some gas tanks recently and shall hereafter be able to store the gas and make tests on different qualities of gas as well as on different types of burners.

Of course, the tests made and reported here as to the effect on various candlepowers of gas burners, under different conditions, are not intended as the most important part of this investigation. We set out to determine it first of all for our standards, but before making the investigation complete, it will be necessary to try different kinds of gas to show the variation with the quality; that we intend to do in the future.

Dr. E. P. Hyde: There is one question I should like to ask

the authors of this paper, and that is whether they have made any investigation or drawn any conclusions from the observations they have made on the relative effect of the vitiation of the air on the luminous value of gas as burned in the different types of burners and on the standard pentane and Hefner lamps. In the photometry of gas every effort is made to have the room ventilated, but some years ago Mr. Bond and myself made some tests in Philadelphia in one of the laboratories of the United Gas Improvement Company to endeavor to determine whether the relative effect of vitiation is the same on gas with the type of burner that was used and on the standard pentane lamp. I think that is a point that might be of some practical importance, and I should like to ask the authors whether they drew any conclusion on that point?

If there is no further discussion, I will call on Mr. Crittenden to close the discussion of the paper.

Mr. E. C. Crittenden (In reply): In regard to Mr. Gilpin's question as to the method of measuring the gas—he remarked that the meter was outside the tank, which is true, but the volume of gas supplied was such as to make the volume constant at the pressure in the tank. During some of the tests the meter was put inside but that caused other troubles. While the meters were outside it was easy to calculate the amount measured outside that would become 5 cubic feet inside.

It is recognized, as is stated in the paper, that all of these results depend markedly on the nature of the gas, and on its richness. The data given can be applied with certainty only to the particular type of gas with which the tests have been made. As to the effect of vitiation, no careful comparison of the effects on the gas and on pentane lamps was carried out. In a general way, the effect is very much the same on the two. I am not prepared to say that it is exactly the same, but it is approximately so. The data which Dr. Hyde has mentioned obtaining in Philadelphia when reduced to the same basis as the curve of Fig. 8 indicate a change of about 3 per cent. in candlepower for 0.1 per cent. of CO_2, whereas Fig. 8 shows 3.4 per cent. As stated in the paper, however, the significant factor is not really the change in CO_2 but the reduction of oxygen in the air. Consequently

when the variation is stated on the basis of CO_2, the magnitude of the effect depends on the way in which the CO_2 is produced.

In regard to Mr. Cady's question—the effects on the arc were much larger than the effects here obtained, and are caused by the rise of temperature with pressure. The phenomenon is quite different in nature from those involved in flames.

ILLUMINATION AND ONE YEAR'S ACCIDENTS.*

BY R. E. SIMPSON.

Synopsis: The paper presents the results of a study of one year's industrial accident records, the purpose being to determine the effect of the lighting conditions in the causation of the accidents. Of the total number 23.8 per cent. were due either directly or indirectly to the lack of proper illumination, and of these 51.6 occurred in the four months having the fewest number of daylight hours. A few typical cases are given showing how the lighting conditions were responsible for injuries to workmen. The use of proper reflectors and care in maintaining proper mounting heights, especially when high efficiency lamps are used, are essential if accidents are to be prevented by good illumination.

There is a widespread belief prevalent to-day that there are approximately 500,000 avoidable accidents per year in this country, and that about one-quarter of this number are caused directly or indirectly by improper lighting facilities. So far as can be learned these figures are estimates made by persons who have had considerable experience in accident-prevention work. There is little evidence to show that any systematic effort has been made to point out the relation between light and accident rate. This is due to the want of statistical data, owing to the enormous labor and expense involved in obtaining such data. A number of men interested in good lighting or in accident prevention, or both, have pointed out the many ways in which the lighting of a factory may influence the accident rate. In some instances studies were made of certain industries, notably by Mr. D. R. Wilson, special inspector in the Factory Inspection Service in Great Britain, who in 1911 and 1912 investigated the lighting conditions in British textile industries and in foundries. In neither one of his reports are there data to enable one to ascertain the percentage of accidents due to the inadequate lighting conditions described.

At about the same time, Mr. John Calder presented a paper before the American Society of Mechanical Engineers, showing the increase in the number of fatal accidents during that part of

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

the year when the ordinary factory working hours, 7 A. M. to 6 P. M., extend beyond the daylight period. The curves presented with his paper showed conclusively that the number of accidents in December and January was 40 per cent. greater than the normal number that might reasonably have been expected if there were the same number of daylight hours in the winter as in the summer.

The records of workmen's compensation and accident insurance companies offer a fruitful field for the study of accidents, provided particular attention is given to details in the investigations. In this respect a few notes on the lighting arrangement will often explain the cause of an accident. The Travelers Insurance Company is particularly fortunate in having over 200 men who are specialists in accident-prevention work. A record is kept of every accident in and about factories, shops, and mills carrying insurance with the Travelers, and all important ones are investigated by the inspectors, who ascertain the conditions that prevailed at the time of the accidents. The reports of these men form an authoritative library on causation and prevention of industrial accidents, and among the causes, and the recommendations for the prevention of future accidents, the lighting question plays an important part.

The main object of this paper is to present the results of a study of these reports covering a period of one year from January 1 to December 31, 1910. All accidents incident to the use of automobiles, teams, bicycles, trolley cars, and slippery pavements are omitted, as well as all accidents occurring in and about coal mines. While there is absolutely no doubt that the darkness of a coal mine, broken only by the feeble light from the miner's lamp, is largely responsible for many coal mine accidents, there are so many other factors bearing on the subject that reliable conclusions cannot be drawn. It is worthy of note, however, that the introduction of electricity for haulage purposes has provided the coal operators with a ready means of lighting the more important switching points in the mines. The use of steel and concrete for roof support, and the application of whitewash to the roof and sides at the turnouts, switching points, and shaft bottoms, materially increases the illumination. Good lighting is es-

sential here in order that the motorman may see that the switches are properly set, and that no standing cars block his way, thus enabling him to avoid derailments and collisions. The other employees at these, the busiest parts of the mine, can also perform their duties much more efficiently and safely because of the better illumination.

Excluding these classes of accidents, there still remain more than 91,000 accidents which occurred in and about industrial plants; and of this number 23.8 per cent. were due, directly or indirectly, to the lack of proper illumination. This figure, 23.8 per cent., corresponds very closely to the estimate of 25 per cent. already mentioned. There is this difference, however, in that the estimate of 25 per cent. was based on avoidable accidents, while the 23.8 per cent. obtained from the Travelers Insurance Company's records embraces both avoidable and unavoidable accidents. It is evident from the records that a large number of the accidents were unavoidable, particularly in those instances where the lighting condition was a contributory rather than a direct cause.

A further analysis of the records shows that 10 per cent. of the total industrial accidents for the year were due primarily to inadequate illumination, and in the remaining 13.8 per cent. the lack of proper lighting facilities was a contributory cause. It is probable that another person in going over these records would arrive at different percentages of direct and indirect causes of accidents due to the illumination, but this would simply represent a difference of opinion in those cases where equally good arguments might be put forth in favor of one view or the other. The essential feature of the analysis is the large percentage of accidents in which the illumination had an important influence.

Under the heading "direct cause" were included all accidents on stairways, in passageways, or in the shop where it was shown that there was no light in the immediate vicinity. It is true that many persons have been injured by falling down stairways that were well lighted, and, therefore, the illumination could have had no bearing on the accident. It is likewise true that if none of the stairways in the country were provided with light, the accident rate from this cause would be vastly increased.

It may be interesting to cite a few typical cases where insufficient or improper illumination was a cause of an accident. In a certain shop having widely spaced lighting units a supporting column cast a shadow which hid a flat 2-inch bar lying at an angle across the passageway on the floor. When one of the front wheels of a truck encountered the bar, the truck axle, swerving sharply to the right, jerked the handle out of the laborer's hand and struck the right foot of a workman standing at the side to let the truck pass. The blow broke one of the small bones in his foot. The sudden stopping of the truck also caused one of the heavy pipes on it to roll off, and the truck handle, acting as a skid, guided the pipe against the workman's left leg, breaking both bones below the knee. It is evident that neither man saw the bar of iron on the floor, a fact which is easily understood when one considers that the floor and the bar were both dark-colored, and further obliterated by the shadow. It is fair to assume that had adequate light been provided, one of the workmen would have seen the bar, and would have removed it instead of attempting to pull a heavy truck over it.

A paper mill employee, while feeding a conveyor with short pieces of pulp wood, noticed that the chute at the other end of the conveyor had become clogged. There was no light at the chute, nevertheless the man after stopping the conveyor attempted to clear the way, and while thus engaged a block of wood slipped out and broke his ankle. There was no occasion for any of the workmen using this part of the mill unless the conveyor or the material caused trouble. This, however, was just the time light was needed and none was provided. The amount of money required to maintain a unit affording ample illumination at this point is negligible when compared with the amount of the claim paid the injured workmen; in fact, such a unit could have been kept burning all day, and every day for a hundred years, and still the owner would have realized a handsome profit; and one employee, at least, would have been saved from injury.

The following two instances represent conditions often seen in certain industries. In the first one, a man fell into a tank containing hot water and acid, and was fatally burned. A number of tanks were placed close together, with narrow walks be-

tween them at the top. There were no guard rails along these walks, and no artificial light was provided, even though the presence of workmen at this point was necessary at odd times of the day. The accident happened just before quitting time in the latter part of December. In the other instance the natural light was not adequate and was supplemented by incandescent lamps. Both the lamps and the windows had a thick coating of grease and dirt, so that by no stretch of the imagination could the illumination be called other than very bad. Nor were there any guard-rails along the walk at the top of the vats containing scalding water. It is not to be wondered at that a workman made a misstep and was scalded to death.

In another case lack of light in the hold of a vessel was, without doubt, responsible for a crushed foot. A workman was piling pig iron there, in semi-darkness, the open hatch, far above, admitting so little light that he could not see that the pile was uneven. While he was still at work the pile toppled over and injured him, as stated. Under exactly similar conditions another workman could not see that a hook was insecurely caught in a bale of cotton that was to be hoisted from the hold of a steamer, and when the hook slipped the falling bale struck the man a glancing blow, breaking his collar bone. In this instance the difference of a few inches in the man's position was all the margin there was between injury and death. In the punch press room of a certain factory an overhead skylight provided plenty of illumination on bright days, but in the winter months, and especially on gray, cloudy days, the daylight illumination was so much reduced as to occasion repeated requests for auxiliary artificial light; and an injured workman based his claim for damages on the ground that the employer had failed to provide sufficient illumination.

Two steam fitters, having finished some work on a temporary platform 9 ft. above the floor, instructed a laborer to remove all supplies and tools. The steam fitters had used an extension cord drop light which they took away with them, thus compelling the laborer to depend on the reflected light from the units below him. He failed to see a short piece of steam pipe, which soon afterward fell on a workman below, fracturing his skull. This

is the type of accident generally classed under the item of "struck by falling material." It is probable that if sufficient illumination had been provided, the laborer would have seen the pipe and taken it away with the other material, thereby preventing the accident; and under the circumstances it is certainly fair to state that the lack of illumination was a contributory cause.

Two trucks being pushed in opposite directions collided on an overhead bridge, and both truckmen were injured by material falling from the trucks. The noise in adjoining shops, in addition to that caused by the trucks themselves, prevented each truckman from hearing the approach of the other. The covered bridge had side windows, but no other means of providing light, and as the accident occurred late in the afternoon in January, the lack of light plus the noise were responsible.

A machine with four saws on one shaft was well guarded, but the drop light had been so arranged by the operator that one of the guards cast a deceiving shadow. The man thought he was placing his hand on the guard, but instead he placed it on the shadow and was badly injured. This was purely a case of improper lighting, and it points out the hazard in the practise of permitting a workman to adjust the lighting units to suit his own convenience, instead of having them placed by a lighting expert who has studied the safety problem carefully.

A workman using an extension cord light found it necessary to use both hands, and he, therefore, made a loop of the cord and hung it about his neck. The worn out insulation of the lamp cord allowed sufficient arcing to set fire to the man's celluloid collar, causing extremely painful burns about the neck and head. In this, as in most other accidents, a great many "ifs" might be thought of; but none of them can hide the fact that there were no permanent means of lighting the section of the shop in which this particular accident occurred.

Finally, there may be mentioned the correlation between a workman's broken wrist and the rather prosaic escape of two hogs from a pen. No doubt all would have gone well had not one of the hogs elected to sleep on the path between two buildings in a plant. True to his name and nature, the hog obstructed the whole width of the path, causing the workman to stumble over

him. There was no means provided to light this pathway, even though it was the direct route between the buildings, and as such was in constant use.

There were several cases where inadequate illumination had impaired workmen's vision, so that these men were subsequently injured while working under lighting conditions that were excellent for normal vision. Their claim that their injuries were due to insufficient lighting was hardly justifiable when applied to the last working place, but it is certain that the impairment of their eyesight due to the poor lighting at their previous workplace had an important bearing on the case.

At the beginning of this investigation an attempt was made to classify the accidents due to the lighting conditions in greater detail than "direct" and "indirect," but this soon proved to be impracticable. If the same proportion had prevailed throughout the records as was evidenced in the first 5,000 cases investigated, the lighting accidents on stairways, passageways, and other seldom-used parts of shops would have had by far the highest rank. It is very generally recognized by illuminating engineers that these are just the places that are likely to be slighted in the original installation, or the maintenance, of factories equipped and operated by the rule-of-thumb method. If one compares the number of accidents that occur at these points, bearing in mind the relatively short time that they are used by a few men, with the number of accidents occurring in the better lighted shops, again having in mind the large number of men and the greater length of time they are subject to the hazards, it is found that the accident rate in the first-mentioned places is abnormally high. It is impossible to draw any other conclusion than that the lack of illumination is largely responsible.

Fig. 1 shows in a diagrammatic form the monthly distribution of all the industrial accidents reported for the year, and Fig. 2 shows a similar distribution of all the accidents caused by inadequate illumination. There is a striking similarity between these curves and those published by Mr. Calder and other investigators. From Fig. 2 the fact may be deduced that 51.6 per cent. of the accidents due to poor illumination occurred in the months of November, December, January, and February, while 48.4 per

cent. occurred in the remaining eight months. This indicates that the likelihood of an accident being caused by poor lighting is more than twice as great in any one of these four months as in any one of the remaining eight months.

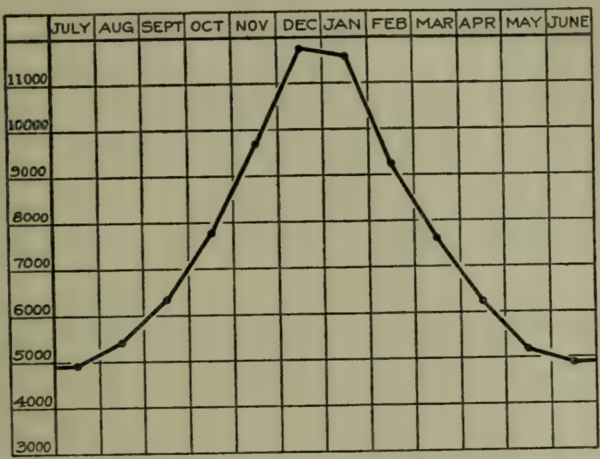

Fig. 1.—Showing the seasonal distribution of all industrial accidents for the year.

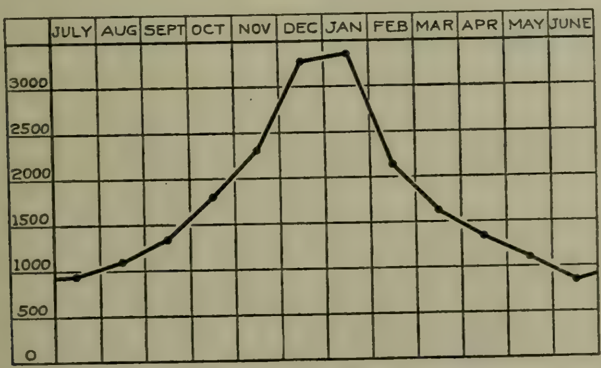

Fig. 2.—Showing the seasonal distribution of all industrial accidents caused by inadequate illumination.

Fig. 3 shows the seasonal distribution of accidents exclusive of those in which the lighting conditions had an influence. It will be noted that the increase in the accident rate in the months of November, December, January, and February is not so pronounced as in Figs. 1 and 2. If the lighting condition was the only factor

contributing to the increase in accidents in the winter months, the curve in Fig. 3 would be practically straight. The similarity of the three curves raises the question as to whether or not a greater number of accidents than those shown were due to the lighting conditions. It is probable that the lack of information in some of the reports is responsible for a certain number of accidents attributed to the lighting conditions being overlooked, but just what this number would be is purely conjectural.

There is another factor which will help to explain the increase in the accident rate in winter months, and in this the lighting conditions play an important part, though it is impossible to obtain any reliable figures. It is partly psychological and partly

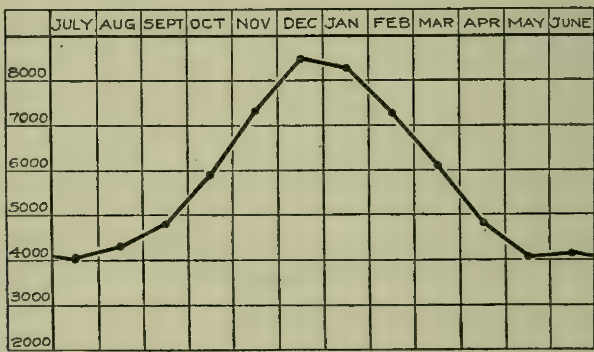

Fig. 3.—Showing the seasonal distribution of all industrial accidents exclusive of those due to inadequate illumination.

physiological, but may be better understood by referring to it as the depressing effect of cold and dreary weather on mankind. It is a well known fact that the members of an exploration party to the Arctic region are carefully selected not only for their scientific attainments, but also for their physical and temperamental fitness to withstand the rigors of the weather and the strain of the long hours of darkness. Notwithstanding this careful selection, the history of almost every Arctic expedition records the failure of some of the men under conditions which would have been easily surmounted if they had prevailed at the beginning of the expedition. The intense cold and the cheerless outlook brought about by the lack of comforts craved by the human body, coupled

with the long stretches of darkness, render the men unfit for their work.

We do not have such extremes of coldness and darkness, nor such lack of associations or bodily comfort, in our industries. On the other hand, our workmen are not selected to bear up under such conditions. Everyone is aware of the depressing effect of a week of overcast skies with a more or less steady rainfall. Substituting cold weather and snow for rain, one can picture the conditions that prevail in the winter months. Colds and other ailments are more prevalent in winter, and the afflicted workmen are less able to guard against injury. Then again there are many buildings where the window area and arrangement affords inadequate illumination on cloudy days, even when it is satisfactory on bright days. This is a condition that is likely to be overlooked by the inspector if he makes an inspection on a bright day. It is quite evident that a large number of accidents might occur under these conditions, and little, if any, thought be given to the underlying cause.

It is hoped at a later date to make a study of the accidents for the year 1915, in order to ascertain what influence, if any, the educational campaign of the Illuminating Engineering Society, the lamp manufacturers, the insurance companies that have studied this matter, and others interested in good lighting, has had on the reduction of accidents. An examination of a few of this year's reports indicates the trend of the times in that five years ago general expressions such as "no light" or "insufficient light" were commonly used in describing the cause of an accident, whereas at the present time we meet with much more definite statements, such as "improperly placed lighting units" or "low-hanging, unshaded lamps." From this one may gather the cheering information that the workmen are gradually appreciating the vast difference between light and illumination. It might be expected that fanciful claims will be made, such as that put forth by an injured workman to the effect that the actinic rays of the lighting unit impaired his vision. The lighting unit in question was a 16-candlepower carbon lamp equipped with a bowl-shaped aluminum-finished reflector.

A statement has been made to the effect that the introduction

of the high-efficiency lighting units was the largest single factor for the increase of accidents in our industries during the period of artificial lighting. This statement is not to be taken as a condemnation of these lighting units, but rather as a protest against the common method of using them. There are hundreds of small manufacturing establishments in this country, each one occupying a single floor or part of one floor in a building. The owners have had the floor wired and connected for central-station service or piped for gas service. They have procured incandescent lamps, gas tips, or mantles, as the case might be, and used them without proper accessories. Of diffusing glass, reflector equipment, mounting height, and other fundamentals of good lighting they either know nothing or care nothing. The workmen adjust the units so that they can "see," the adjustment generally consisting in placing the lighting unit close to the work, very often between the man and the work, and almost always in the direct line of vision. The carbon lamp or the open-flame gas light contributed a distinct hazard under these conditions, and the hazard was greatly increased when the high-efficiency incandescent gas mantle and electric lamp were substituted without any other change being made at the same time.

In some cases the meterman is the only public utility representative to visit these small manufacturing concerns, and very little advice on the lighting conditions is given by these men. The consulting engineer or lighting expert is seldom, if ever, called in to give advice on installations where the total connected lighting load is in the neighborhood of one kilowatt. In the larger manufacturing plants the lighting bill will bear about the same proportional relation to overhead expense as it does in the small shop, although the bill itself will be many times larger. Economy has generally influenced the management in securing expert advice on the lighting question with a noticeable improvement in the illumination. This in a measure accounts for the modern lighting equipment in the large plants and also shows why they compare so favorably with the small establishments. A workman may be just as seriously injured in a small shop as in a large one; in fact, the accident rate due to the lighting conditions is likely to be higher in the small shop than in the large

shop doing the same class of work. The accident insurance companies are assuming risks in the small shops as well as the large ones, and once a policy is written the premises must be inspected periodically. It is the duty of the inspector to prevent accidents by recommending changes in conditions which tend to cause injuries to workmen. Since inadequate and improper illumination is recognized as a cause of accidents the insurance company inspector tries to improve the lighting conditions, and in this capacity he is probably the most potent factor for improving the illumination in the small shops.

In the past year the gas-filled tungsten lamp has become an established commercial product in a constantly increasing range of sizes for multiple circuits. The concentrated filament of this lamp, more nearly approaching a point source, coupled with its higher intrinsic brilliancy as compared with other tungsten lamps, makes the use of reflectors absolutely essential. The manufacturers are earnestly insistent that users equip these lamps with proper reflectors, but unfortunately this advice is not always followed. In some instances shallow dome-type reflectors were used with the vacuum-type tungsten lamp, but when the gas-filled lamps were substituted no change was made with respect to the reflector equipment or mounting height, even though the light sources were within the range of vision. Excellent results in the way of diffusion and distribution can be and have been obtained by the use of the dome-type reflector with the gas-filled tungsten lamp, but when viewed from the safety standpoint they should never be used together, unless the mounting height is such as to preclude any possibility of the lighting source being within the range of vision. Unless this principle is followed it is inevitable that the eyesight of the workmen will be impaired, and with impairment of a workman's eyesight comes a greater likelihood of injury.

DISCUSSION.

MR. G. S. BARROWS: There are a number of inspection organizations who make a practise of visiting their clients and advising them regarding the various hazards and the best methods of overcoming them. I think from what I have seen of them,

however, that on the subject of proper illumination they are not as well grounded as they might be and I believe it is a very desirable thing for central station companies to get in as close touch with such inspection bureaus as possible, in order to advise them as to the proper steps they should take to provide adequate illumination. On the eleventh page of this paper there is a suggestion which I think is a very fruitful one; Mr. Simpson says, "In some cases the meter man is the only public utility representative to visit these small manufacturing concerns, and very little advice on the lighting conditions is given by these men." Now what I am going to say applies rather more to the gas than the electric central station; nearly all gas companies have a maintenance department for taking care of incandescent gas lamps; there is no reason at all why the maintenance men should not be given a very thorough training in the proper placing of lamps. They cannot, of course, become illuminating experts but they can be so instructed that they will be able to recognize hazards; and while they may not be able to give the best suggestions for overcoming the hazard, they could fill in reports regarding the placing of lamps, etc., which would enable a representative of the illumination department to inspect the various plants and make suggestions for improving the lighting conditions. I don't know that that is being done by any company in this country, but I believe it is something that the companies ought to begin to do, and I can say that at least one company is going to take this matter up immediately.

MR. G. BERTRAM REGAR: The Philadelphia Electric Company has recently organized a department known as the lighting service department, practically along the lines as suggested by Mr. Barrows. The headquarters of the department are at the central office. Here the lighting experts are stationed, and a complete system of data, instruments, and records of cases investigated are kept. A representative of the department is stationed at each of the district offices, whose duty it is to constantly make inspections, by day and night, of consumers' installations and advise the consumers having inefficient installations as to changes to remedy the defects. The lamp boys are being educated to a better understanding of illumination and it is their duty when

making lamp renewals to report poor installations. The installation men and meter men also have a blank form to notify the lighting service department. In cases of complaints on bills, after the meters have been tested and the results explained to the consumer, the lighting service department is notified, in order that they may make a thorough inspection for the purpose of possibly offering suggestions for a more efficient installation. The whole policy, as can be seen, is to ever improve the service to the consumer.

MR. J. L. MINICK: In reading this paper it has been my impression, probably an erroneous one, that Mr. Simpson believes that the high percentage of accidents during the winter months can be attributed largely to lighting conditions. This does not seem to me to be the impression that should be given; not because we do not wish to prevent accidents so far as it is possible, but because a study of the curves shown in the paper indicates that there will be a greater number of accidents during the winter months regardless of lighting or any other condition.

MR. R. E. SIMPSON (In reply): The two concrete cases cited by Mr. Barrows emphasize the importance of not depending too much on the ideas of the workmen on the lighting question, and in particular on the location of local lamps. In almost every shop may be found some workmen who can tell just where they want a lighting unit to be placed, and it will be found that their ideas conform to illuminating engineering principles. We must not lose sight of the fact that this class of workmen is in the minority. There were thousands of cases noted in the investigation where men were employed on drilling machines and similar operations, where drop lamps, usually unshaded, were depended on for illumination. The lamps are usually placed close to the work while the controlling mechanism is above the head. While watching the work or even when looking up the men often place a hand in the gears instead of on the controlling wheel. A crushed hand or finger is very probable under these conditions. I am sure that all who are interested in good lighting and accident prevention work will be glad to cooperate in the plan advocated by Mr. Barrows.

It is to be regretted that definite information on the cost of

industrial accidents is not available. There are so many varying factors such as the face or amount of the policy, the seriousness of the accident, attorney fees, etc., that it is hard to arrive at an average. The 15-watt lamp burning 100 years would cost only one half as much as was paid to the injured paper mill employee. Another man receiving the same kind of injury might receive twice as much, or only one half as much, depending on the factors already mentioned.

There was no intention of ascribing the high accident rate in winter months to poor illumination solely. The curves clearly indicate this, in that their general outline is the same. These curves tend to prove that the number of accidents caused by poor lighting are twice as high in the winter months as in the summer months. It is in the winter months that artificial light must be depended on to a greater extent than in the summer months. In the latter part of the paper other factors influencing the accident rate in winter are discussed. Mr. Minick's discussion really opens up the whole subject of accident prevention and is too broad to be thoroughly treated here.

INDUSTRIAL LIGHTING WITH MERCURY-VAPOR LAMPS.*

BY WILLIAM A. D. EVANS.

Synopsis: In the following paper, the mercury-vapor lamp is treated as strictly an industrial illuminant and it is intended to give an idea of its various industrial uses and the practise now in vogue. Considerable data from actual installations are given which should enable those contemplating installing lamps to follow out the lines already established. The variety of industries in which these lamps are used embraces practically every operation in machine shops, foundries, textiles, printing, glass manufacturing, motion picture studio lighting, etc. In each of the departments in which mercury-vapor lamps are used, the lamps have a certain peculiar adaptation for that class of work; for instance, metal working plants, in the making of moulds; the grinding and polishing departments, and in the body finishing and varnishing departments of wood-working plants, where slight flaws, scratches, blemishes, etc., are easily detected. In machine work there is very little reflection from bright and shiny parts; in the testing department for engines and in foundries, the light penetrates the atmosphere; in textile manufacturing and in the inspection of all kinds of finished products, the magnifying quality of the light makes details easily perceived; and in motion picture studio work, the softness of the light, its high actinic value and diffusion and ease on the eye are especially desirable. Numerous photographs are shown and a bibliography of articles on lighting with mercury-vapor lamps is given.

INTRODUCTION.

Artificial lighting in interiors may roughly be divided into two classes, esthetic and industrial; esthetic embracing the lighting installations where the idea prevails of harmonizing the illumination with surroundings; and industrial covering the lighting of manufacturing plants where the prime consideration is to enable the eye to do its work with the greatest rapidity and least fatigue.

Mercury-vapor lamps on account of the peculiar bluish-green color of the light and the tubular form of the light source may be classified as strictly an industrial illuminant.

Among the advantages derived from these characteristics, which makes the light particularly desirable for industrial lighting, are visual acuity, low intrinsic brilliancy and natural differences.

The first mercury-vapor lamps for industrial lighting purposes were installed in the composing room of the old building of the *New York Evening Post* during the summer of 1903. Two 200-watt lamps were placed over the make-up tables. From this small installation in a printing plant has developed the use of

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

mercury-vapor lamps for industrial lighting in all of its different branches, and at the present time one metal working plant alone is using a total of about 2,500 tube lamps.

Classification of Industries Where Mercury-Vapor Lamps are in Use.—The industries in which mercury-vapor lamps have been successfully used are many and varied, and while it has not been possible to collect data regarding every operation which is carried on under the lamps, an attempt has been made to gather sufficient material which will enable anyone contemplating installing lamps to follow the practise which has been carried out for similar classes of work. To attempt to classify the entire industrial field would be far beyond the scope of this paper, and it is only possible to give a broad classification. The general divisions will be given below and the lighting of each operation treated separately.

Table I—General classification of industries in which mercury-vapor lamps are used for illumination.

- Metal working plants.
    - Foundries.
    - Forge and blacksmith shops.
    - Machine shops.
    - Erecting and heavy machine shops.
- Woodworking plants.
- Varnish and finishing plants.
- Textile plants.
    - Silk mills.
    - Cotton mills.
    - Woolen and worsted mills.
    - Knitting mills.
    - Embroidery plants.
- Newspaper and printing plants.
- Paper manufacturing.
- Clothing manufacturing.
- Power houses.
- Glass manufacturing.
- Shipping and storage.
- Motion picture film manufacturing.
- Miscellaneous.

In the installations referred to, the lamps used consist of four different types, the 20-in. (50.8 cm.) type for direct current designated as the 200-watt lamp (nominally 192.5 watts) and the 50-in. (1.27 m.) lamp for direct current and alternating current, both designated as 400-watt almps (nominally 385 watts) and the quartz or high pressure lamp for direct current designated as a 725-watt lamp.

METAL WORKING PLANTS.

The illumination of metal working plants probably offers the largest field for the use of mercury-vapor lamps, not only on account of the size of the industry, but due to the manner in which marks and imperfections on metal stand out under the light. The use of mercury-vapor light is found throughout the entire field from the making of moulds, where slight blemishes in the sand are perceived, through the different manufacturing processes up to the final inspection of the finished product.

Foundries.—The lighting of a foundry may roughly be divided into three different parts; moulding, embracing core making; casting floor and the finishing operations, embracing tumbling, chipping and cleaning. For none of these is there a particular large amount of light necessary. Most foundries are dark holes at night, and even in the daytime, during the period of pouring off, it is extremely difficult to see down the floor on account of the vapor in the atmosphere. It should be borne in mind, however, that accidents are a very frequent occurrence and too much light cannot be provided to guard against the dangers of workmen falling over moulds, kettles and castings, which may happen to be in the way. Lamps should be placed out of the field of vision as far as possible.

The following table shows a number of different foundries varying in size, which are lighted by mercury-vapor lamps with data relative to the energy consumption.

MOULDING DEPARTMENTS.

	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height above floor, Feet
1	6,680	725	0.33	22
2	14,170	400	0.27	15–27
3	22,225	400	0.56	12
4	4,920	400	0.31	15
5	83,500	200–400	0.21	18

CASTING FLOOR.

	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height above floor, Feet
1	15,200	725	0.52	22
2	12,400	725	0.23	27
3	24,000	725	0.24	45
4	28,180	725	0.34	22
5	5,000	725	0.29	42
6	44,000	400	0.20	27
7	44,500	400	0.55	12
8	16,300	400	0.30	20
9	30,800	400	0.31	23–35
10	6,900	400	0.31	15
11	13,400	400	0.28	16
12	90,500	400	0.34	18
13	12,000	400	0.26	18
14	28,350	200–400	0.29	18
TUMBLING, CHIPPING AND CLEANING.				
1	25,500	400	0.29	21
2	16,300	400	0.33	13
3	4,400	200	0.32	10

Forge and Smith Shops.—For this class of work where there is apt to be moving machinery and high machines, the quantity of illumination should be somewhat greater than in the foundries. Welding, case-hardening and tempering are included under this designation. Data on typical installations for this class of work are given below.

	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Forge shop	24,430	725	0.60	33
2. Forge shop	14,000	725	0.31	27
3. Forge shop	26,000	400	0.29	23
4. Forge shop	3,780	400	0.71	15
5. Forge shop	3,000	400	0.77	10
6. Forge shop	13,820	200	0.17	14
7. Flange shop	16,900	725	0.21	30
8. Smith shop	16,800	725	0.35	27
9. Smith shop	61,380	725–400	0.37	24–34
10. Welding	11,700	400	0.39	14
11. Welding	3,424	400	0.24	20
12. Case hardening	2,770	200	0.82	12
13. Tempering	1,200	400	1.28	9

Machine Shops.—Machine shops may be roughly defined as all shops where metal is worked with the purpose of reducing or altering the shape by means of cutting away a certain portion

of the material. This will embrace the use of lathes, shapers, millers, planers, drill presses, automatic machines, punch presses and so forth. Closely allied to this class of work is the assembling or erecting of the finished pieces, and the inspection of the parts and final product. There are other operations which are so closely related to machine shop work that they are included under this heading.

The machine shops listed below are all lighted entirely by the use of mercury-vapor lamps without any individual lamps of the machines, except in very few cases where it is necessary to bore inside of castings or some such similar work, which would necessitate the use of individual lamps even with the best daylight. Due to the low intrinsic brilliancy and the absence of bright spots with the tube lamps, the reflection from bright metal parts is kept at a minimum.

MACHINE WORK WITH SMALL TOOLS.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet	
1. Miscel. small tools ..	22,800	400	0.66	11	Gear cutting
2. " " " ..	25,240	400	0.62	14	Auto parts
3. " " " ..	11,400	400	1.12	30	Gen. mach. wk.
4. " " " ..	4,800	400	0.92	12	"
5. " " " ..	2,190	400	0.95	12	"
6. " " " ..	5,840	400	0.73	12	Ball bearings
7.* " " " ..	54,650	400	0.52	13	Auto engines
8. " " " ..	30,950	400	0.92	13	Auto parts
6. " " " ..	14,880	400	0.63	22-28	Breech mechanism
10. " " " ..	12,180	400	0.95	10	Revolver parts
11. " " " ..	38,980	200-400	0.60	14	Air brake parts
12. " " " ..	10,800	400-200	0.50	12	Auto parts
13. " " " ..	8,736	200	0.88	9	Gun parts
14. " " " ..	20,520	200	0.68	9	"
15. " " " ..	7,760	200	0.89	9	"
16. " " " ..	5,750	200	0.80	9	"
17. " " " ..	5,175	200	0.75	9	"
18. " " " ..	14,700	200	0.55	10	Auto parts
19. " " " ..	5,400	200	0.57	10	"
20. " " " ..	7,800	200	1.18	14	Torpedo mfg.
21. Tool room	11,760	200	0.92	11-14	
22. " "	2,500	400	0.80	12	
23. " "	6,750	400	0.80	14	
24. " "	3,240	400-200	0.71	12	
25. Drill presses	1,790	200	0.65	12	Auto parts

MACHINE WORK WITH SMALL TOOLS.—(*Continued.*)

	Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
26.	Milling machines ...	12,220	400	1.15	10
27.	" " small	12,220	400	1.18	10
28.	Lathes	12,220	400	0.79	10
29.	Reamers	12,220	400	1.12	10
30.	Model making......	12,220	400	1.22	10
31.	Screw machines.....	12,390	200	0.81	8
32.	" "	5,188	200	0.75	8
33.	" "	11,200	400	1.00	12
34.	Saw finishing.......	900	400	1.28	10

* A night photograph of this installation is shown in Fig. 1.

The above machine shops are all those where only small tools are employed. Where large engine lathes, boring machines and similar tools are used for working on heavy castings or material which generally necessitates the use of an overhead travelling crane, the lamps are usually placed above the cranes or under the crane rails. These shops are designated as heavy machine shops and the following data relates to them.

HEAVY MACHINE WORK.

	Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet	
1.	Heavy machine work	300,000	725	0.18	40	Structural steel
2.	"	23,350	725	0.65	50	Shrapnel mfg.
3.	"	28,000	725	0.52	45	"
4.	"	69,600	725	0.62	30-48	"
5.	"	14,900	725	0.39	18	"
6.	"	14,500	725	0.40	18	"
7.	"	8,250	725	0.35	18	"
8.	"	6,980	725	0.52	25	Torpedo mfg.
9.	Large lathes........	14,335	725	0.71	35	Eng. mfg.
10.	"	29,400	400	0.59	12	Shrapnel mfg.
11.	"	19,700	400	0.64	12	"
12.	Heavy machine work	11,250	400	0.57	24	Car Wheels
13.	"	45,780	400	0.48	20-50	Large gun mfg.
14.	"	22,800	400	0.44	25	Loco bldg
15.	"	17,860	200	0.63	23	"
16.	"	11,400	200	0.44	14	"

Punch Presses.—Punch press lighting requires lighting somewhat different from the ordinary machine shop as it is necessary for the light to shine in and around the dies and to a certain extent the light will be blocked off by the frame of the press. Moreover, extreme care must be taken not to have dazzling light sources in

the field of vision, for if the eye happens to be momentarily blinded, it may mean the loss of a finger for the operator. While the following table gives data for typical lighting of punch press rooms, however, each installation should be treated separately and the lamp located with reference to the machines.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Press room	8,750	400	0.78	12
2. "	11,750	400	0.55	12
3. "	18,400	400	0.76	36

Grinding and Polishing.—Another operation which is somewhat distinctive from regular machining is that of grinding, polishing or buffing. Extremely good illumination is necessary for these, as slight flaws and scratches must be detected easily and rapidly by the men while working.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet	
1. Grinding.	49,980	200	0.26	14	Rim grinding
2. "	1,230	200	0.63	12	Auto parts
3. Polishing............	1,510	400	0.80	12	Plated silver
4. "	8,310	400	0.72	14	Revolver parts
5. "	2,090	200	0.74	9	Gun parts
6. "	1,280	200	1.20	12	Engine valves

Boiler, Tank and Plate Shops.—Another class of large shops is embraced under the classification of boiler, tank and plate shops where large pieces of sheet metal are worked up for use. This class of shops as a rule requires very little general lighting as a good part of the work is carried on inside of the boilers and tanks, and local lighting is necessary.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Boiler shop	30,624	725	0.24	45
2. Boiler shop	26,400	725	0.41	36
3. Boiler shop	12,220	400	0.50	20
4. Tank shop	18,000	725	0.28	35
5. Tank shop	18,000	400	0.34	18
6. Tank shop	6,000	400	0.33	24
7. Tank shop	12,000	400	0.40	20
8. Plate shop	46,900	400	0.15	28

Assembling and Erecting.—The final operations in most metal working plants is the assembling or erecting of the finished parts. Here the lighting is apt to vary between wide limits depending upon the nature of the product. The following data give in-

formation relative to assembling of parts in different industries.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Asmblg. revolver parts	12,220	400	0.75	12
2. Asmblg. auto parts....	6,192	200–400	0.81	12
3. Asmblg. automobiles...	11,566	200–400	0.59	12
4. Asmblg. locks..........	3,264	200	0.94	10
5. Asmblg. gun parts.....	6,180	200	0.88	9
6. Erectg. locomotives*...	30,625	725	0.28	45
7. Erectg. locomotives....	30,400	725	0.29	51
8. Erectg. cars...........	117,000	400	0.30	20–29
9. Erectg. cars...........	24,000	400	0.40	25–37

* A night photograph of this installation is shown in Fig. 2.

Testing Departments.—With certain machinery it is absolutely essential that it be thoroughly tested under service conditions and in numerous cases 24 hours or longer tests are run, necessitating as good lighting at night as during the day. In testing automobile engines, particularly this condition occurs and due to the large amount of fumes and smoke in the atmosphere, the mercury vapor lamps have proven particularly desirable on account of the penetrating power of the green light. Good illumination is very important as it is often necessary to adjust the carburetors, magnetos, etc.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Testing large machines	7,840	725	0.65	25
2. Auto engine test*......	12,750	400	0.41	14
3. Auto engine test.......	19,200	400	0.75	12

* A night photograph of this installation is shown in Fig. 3.

Inspection Departments.—Inspecting might be termed the most important operation in the entire shop as every part that passes an inspection and proves defective in the hands of a customer, gives the manufacturer a bad reputation. The value of good illumination in this department cannot be too strongly dwelt upon.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Inspectg. revolver parts	6,110	400	0.75	12
2. Silverware inspection...	3,400	400	0.82	12
3. Inspectg. auto parts....	1,230	200	0.63	10
4. Inspectg. browning.....	6,550	200	0.94	10
5. Inspectg. gun parts....	12,390	200	0.88	9

WOODWORKING PLANTS.

The lighting of woodworking plants is similar to that of machine shops, inasmuch as the machines must be adequately

illuminated to prevent accidents, and it is necessary to see the marks on the material. In most cases the grain of the wood stands out particularly clear under the green color of the mercury-vapor lamp.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet	
1. Planning mill	30,000	400	0.28	20	Car parts
2. "	7.000	400	0.35	17	"
3. Carpenter shop ...	3,640	400	0.69	12	Genl. carpenter wk.
4. Woodworking shop	3,000	400-200	1.28	8	Carriage bodies
5. Carpenter shop ...	9,000	400-200	0.39	15	Rough carptr. work
6. "	12,390	400-200	0.56	15	Genl. carpenter wk.
7. Woodworking	6,795	200	0.91	10	Gun stocks
8. "	4,807	200	0.96	10	" finishing
9. Carpenter shop ...	5,600	200	0.83	10	Box making
10. "	5,400	200	0.71	9	"
11. Woodworking	6,550	200	0.94	10	Stock inspection
12. "	7,775	200	0.50	10	Auto bodies

VARNISHING AND BODY FINISHING SHOPS.

Closely akin to woodworking shops are the varnish shops where the finish is placed on a great many articles. Under the same heading is included "Body Finishing" which embraces the painting and finishing of automobile bodies. This latter is an extremely important item in the automobile business, as the finish on the car is the first point to strike the average purchaser. This work is generally done in a long narrow room with windows on one side, and the dark rooms on the other. The room is kept closed throughout the process in order to keep out insects and the temperature is maintained at a constant point. When working in daylight it is necessary to turn the bodies, after rubbing down, to obtain light on the opposite side. This, however, has been obviated by the use of two rows of mercury-vapor lamps with angle reflectors, throwing light on both sides of the body and permitting the work to be done in a great deal less time.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet	
1. Varnish shop	3,756	200	0.82	10	Gun stocks
2. "	3,100	200	0.75	10	"
3. Body finishing*	4,400	400	2.28	8½	Auto
4. "	2,800	400	2.86	8½	"

* A night photograph of this installation is shown in Fig. 4.

TEXTILE MANUFACTURING.

The lighting of textile plants varies somewhat from that of machine shop lighting. In almost all cases the machines are entirely automatic and the necessity for seeing generally occurs when a thread breaks which automatically stops the machine. Until this thread is repaired that portion of the work is at a standstill and every second saved in quick repairs means just so much more output. As the threads in silk work are as fine as one two-thousandth of an inch, not only is a large amount of light necessary, but also a light with high visual acuity.

Silk Mills.—The first operation in silk is what is known as "throwing," which is simply twisting and doubling the threads over and over again to work them up to the required thickness. Winding and spinning are also a similar operation, and the following data will cover all of these operations.

PRELIMINARY OPERATIONS.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Reeling	2,091	400	0.95	9
2. Reeling	4,400	400	1.40	10
3. Spinning	4,185	400	1.00	12
4. Winding	16,200	400	0.50	12
5. Spinning	7,040	400	0.80	12
6. Spinning	10,032	400	1.47	10
7. Spinning	3,000	400	1.02	12
8. Spinning	28,020	400	0.73	10
9. Winding	6,790	400	0.69	12
10. Winding	3,000	400	0.77	12
11. Doubling	4,680	400	0.82	10
12. Winding	20,448	400	0.57	10
13. Reeling	2,150	200	0.54	8
14. Reeling	840	200	0.69	10
15. Spinning	6,465	200	0.48	9
16. Winding	6,220	200	0.69	9
17. Twisting	8,515	200	0.59	9
18. Winding	1,680	200	0.69	10
19. Spinning	3,400	200	1.02	10
20. Winding	2,520	200	0.69	10

Warping and Quill Winding.—After the silk has been worked up to the proper thickness and twisted, a portion of it is sent to the warping department and the balance to the quilling department.

In the warping operation, the silk is unwound from small spools onto a large drum or beam, from which it is rewound on the warp and placed in the loom. The balance of the silk is wound up into small bobbins which are placed in the shuttles of the loom.

Good illumination is even more necessary for these processes than for the throwing operations.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Warping	10,780	400	1.11	12
2. Warping	10,906	400	1.16	12
3. Warping	2,940	200	0.53	10
4. Warping	7,100	400	1.08	10
5. Quill winding..........	2,020	400	1.51	10

Entering.—When the warp is finished, it is necessary to thread it through reeds of the harness before the warp can be placed on the loom. Automatic machines are in use for this work, but a great deal of it is done by hand and requires a high degree of illumination.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Entering	2,800	400	1.65	12

Weaving.—The main operation in silk is weaving, as this produces the goods in the final form. Broad silk looms are generally lighted by using one 400 or 200-watt mercury-vapor lamp to every four looms, while for ribbon looms one or two 200-watt lamps are used per loom.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Broad silk	11,800	400	1.00	14
2. Broad silk	7,620	400	1.47	12
3. Broad silk	11,508	400	1.27	11
4. Broad silk*	10,780	400	1.21	11
5. Broad silk	10,906	400	1.27	11
6. Broad silk	10,045	400	1.30	11
7. Broad silk	8,890	400	1.37	10
8. Broad silk	29,295	400–200	1.18	14
9. Broad silk	6,000	400–200	1.15	8
10. Broad silk	11,508	400–200	1.6	11
11. Broad silk	7,285	400–200	0.73	10
12. Broad silk	6,340	200	0.55	10
13. Ribbon looms	750	200	1.54	9
14. Ribbon looms	4,800	200–400	0.84	12

* A night photograph of this installation is shown in Fig. 5.

Picking and Inspecting.—After the silk comes from the loom, it is carefully gone over and picked, which consists of removing the knots and loose ends and the detection of other flaws which may have occurred through the carelessness of the weaver.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Picking	2,800	400	1.65	12
2. Picking	340	200	1.39	10

Cotton.—The lighting of cotton mills in the arrangement of lamps is somewhat similar to that of silk, with the exception that due to the greater thickness of the threads, less light is needed.

Preliminary Operations.—The preliminary operations consisting of lapping, carding, drawing, spooling and spinning are somewhat along the line of the throwing operation in silk manufacturing, the purpose being to prepare the cotton for the loom.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Carding	600	200	0.23	10
2. Ring spinning	3,330	200	0.47	10
3. Ring spinning	12,000	200–400	0.68	12
4. Twisting	15,170	200–400	0.68	12
5. Winding	3,660	200–400	0.58	10
6. Warping*	1,500	200	0.64	12
7. Beaming	1,760	200	0.44	12

* A night photograph of this installation is shown in Fig. 6.

Weaving.—In cotton weaving the looms are generaly lighted by one 400-watt mercury-vapor lamp to approximately every 14 looms or one 200-watt lamp to about every eight looms, depending somewhat on the arrangement and size of the looms.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Weaving (coarse goods)	25,200	200–400	0.52	15
2. Weaving (coarse goods)	26,000	200	0.37	12
3. Weaving (coarse goods)	21,573	200	0.45	10
4. Weaving	36,570	400	0.74	12
5. Weaving	4,580	200	0.78	9½
6. Weaving	21,000	400	0.66	14

Finishing.—The finishing operation in cotton consists practically of cleaning the goods, and is the final preparation for the market.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Finishing	6,080	400	0.64	12

Fig. 1.—A machine shop illuminated by mercury-vapor lamps.

Fig. 2.—Locomotive shop illuminated by mercury-vapor lamps.

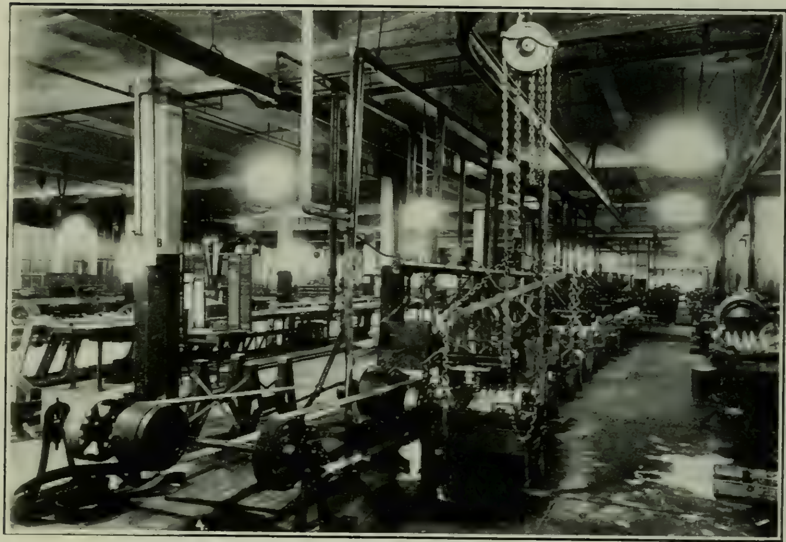

Fig. 3.—Automobile test shop illuminated by mercury-vapor lamps.

Fig. 4.—Automobile body finishing department illuminated by mercury-vapor lamps.

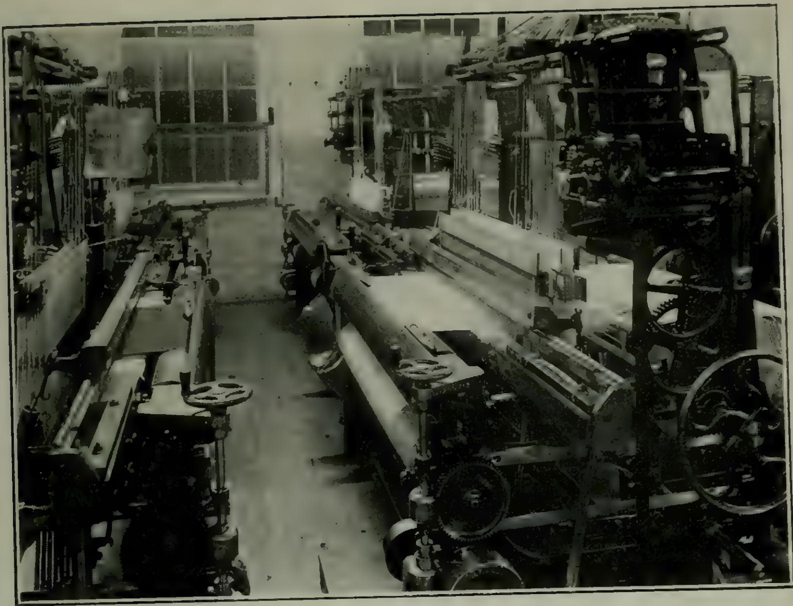

Fig. 5.—Silk looms illuminated by mercury-vapor lamps.

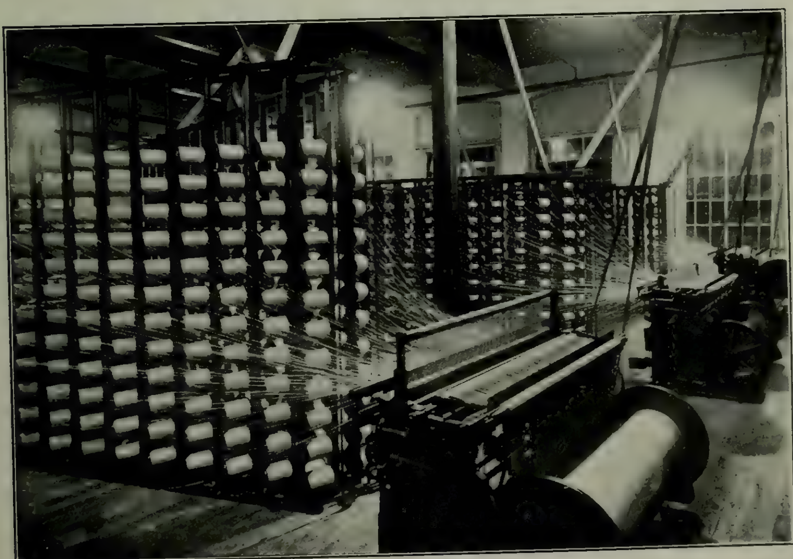

Fig. 6.—Cotton warp department illuminated by mercury-vapor lamps.

Fig. 7.—A roving department illuminated by mercury-vapor lamps

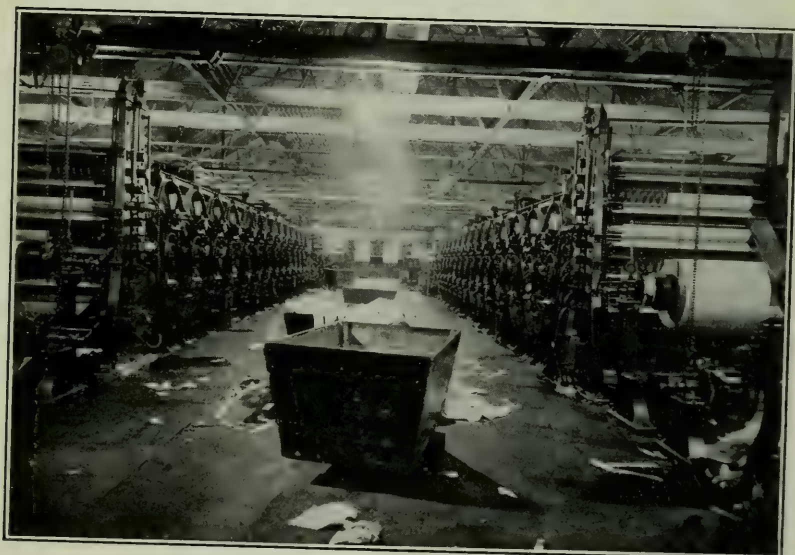

Fig. 8.—Paper machine room illuminated by mercury-vapor lamps.

Fig. 9.—A power plant illuminated by mercury-vapor lamps.

Fig. 10.—A plate glass inspection department illuminated by mercury-vapor lamps.

Fig. 11.—Craneway illuminated by mercury-vapor lamps.

Fig. 12.—Interior of a moving picture studio.

Woolen and Worsted.—The preliminary operations in woolens and worsted consist in scouring the wool to remove the grease, then carding, combing, spinning and so forth in preparation for the looms, simlar to other textile operations.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Carding and roving*...	26,000	400	0.30	14
2. Carding	6,000	200	0.23	10
3. Mule spinning.........	5,400	400	0.57	10
4. Winding	2,000	200	0.58	10
5. Spinning	6,600	200	0.30	10
6. Spinning	13,728	200–400	0.53	12
7. Winding	6,500	400	0.94	10
8. Spinning	26,000	400	0.30	14
9. Winding	26,000	400	0.30	14

* A night photograph of this installation is shown in Fig. 7.

Weaving.—In woolen and worsted weaving, the amount of light necessary and the arrangement is very similar to that in cotton mills.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet	
1. Weaving	3,750	400	1.13	10	Special goods
2. "	60,000	200	0.64	12	
3. "	58,880	200	0.78	9	
4. "	58,880	200	0.71	9	

Finishing.—The finishing operation is similar to cotton,, though somewhat more exacting.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Finishing	2,670	200	0.43	10
2. "	2,375	200	0.57	10
3. "	6,600	200	0.35	10

Knitting Mills.—In knitting, the preliminary operations are similar to those in woolen manufacturing and the data given above will cover these. After the wool is wound on the bobbins, it is placed in the knitting machines, and worked up into the desired form.

Class of work	Total sq. ft	Watts per lamp	Watts per sq. ft.	Height Feet
1. Knitting machines........	6,500	400	0.94	10
2. "	4,600	200	0.67	10
3. "	15,000	200	0.56	11

Stitching Department.—After the goods are taken off the machines, it is necessary to inspect carefully and sew up the defects. This is done in the stitching departments.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Stitching machine	5,200	400	1.33	10
2. Stitching machine	6,500	400	0.94	10
3. Cutting room..........	4,500	200	0.43	12

Embroidery Plants.—Embroidery machines can be satisfactorily lighted by providing sufficient general illumination to adequately light all parts. The machines are about 30 to 40 feet (9.14 to 12.19 m.) long and lamps are generally placed directly over them.

The working out of the patterns is accomplished by means of a pantagraph. On most machines this is guided by hand, though in some large plants it is operated automatically.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Automatic machine	19,200	400	0.95	14
2. Hand machines.........	2,400	200	2.00	10
3. Hand machines.........	2,750	200	0.98	9

NEWSPAPER AND PRINTING PLANTS.

The illumination of newspaper and printing plants covers the lighting of composing room, stereotype, press and mailing rooms, all of which will be treated separately.

Composing Rooms.—In a number of composing rooms, the make-up tables are equipped with inverted V-shaped racks placed over the tables, and 200-watt mercury-vapor lamps are placed in under these racks.

For other tables and banks, lamps are hung directly from the ceiling, and provide general illumination throughout the room. Linotype machines are lighted by overhead lamps to cover the repairs to the mechanism, but small individual lamps must be placed on each machine to light the slugs.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet	
1. Newspaper composing	2,515	400	2.3	12	
2. "	6,075	400	1.51	12	
3. "	9,400	200-400	0.72	14	Incl. linotypes
4. "	3,120	200-400	1.84	10	
5. Printing plant	12,400	200-400	1.92	9	
6. "	6,085	200-400	1.45	10	
7. Newspaper composing	6,300	200	1.47	8	
8. "	480	200	3.2	6	Rack lighting
9. "	3,430	200	2.4	8-12	
10. Printing plant	1,218	200	1.58	9	
11. Newspaper composing	1,200	200	1.55	11	
12. "	1,480	200	1.70	10	
13. "	3,500	200	1.70	10	
14. Linotype machines...	2,205	400	0.70	12	Supplemented by individual lamps on machines.

Stereotype Room.—After the forms are made up in the composing room, impressions are made of them on the matrix, and this is taken to the stereotype room where the cylinders are cast from them to go on the presses. This lighting is somewhat similar to that of machine shop lighting, as the plates also have to be trimmed and cut to size.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Stereotype room	1,500	400	1.03	12
2. "	1,000	400	0.77	10
3. "	2,410	200	0.48	10
4. "	880	200	0.44	16

Press Rooms.—Press rooms have been lighted either by general illumination or by placing lamps directly on the presses in newspaper work, or by a combination of the two methods.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet	
1. Newspaper presses ..	6,000	400	0.83	14	
2. "	1,000	400	1.54	15	
3. Magazine presses....	9,800	400	0.55	15	
4. Newspaper presses ..	7,980	400	0.48	10	
5. "	4,000	200	1.05	8-15	Some lamps on presses
6. "	7,320	200	0.84	8-14	"
7. "	2,875	200	0.94	10	
8. Job presses	650	400	1.19	12	
9. Newspaper presses ..	5,150	200–400	0.82	27	
10. Small power presses.	7,728	400	1.82	10	Engraving presses
11. Hand presses	12,100	400	1.95	10	"
12. Paper handling mach	7,250	200	0.53	9	

Mailing Room.—The work in the mailing room consists of wrapping and addressing papers or magazines and requires a fairly good general illumination.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Mailing department	4,485	400	0.52	12
2. Mailing department	4,180	200	0.46	10

PAPER MANUFACTURING.

Paper manufacturing consists essentially of four operations: the grinding room where the wood is ground up, the beater room where the pulp is mixed, the machine room, and for high grade paper manufacturing, the calendar room, which is equipped with machines for putting on the finish. Not a great deal of light is necessary to see these different operations as not many of them are particularly fine work, but sufficient illumination must be provided to obviate any possibility of accidents.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Grinding room	2,400	400	0.50	20
2. Beater room	9,000	200	0.13	10
3. Machine room*	8,000	200	0.38	10
4. Machine room	4,000	725	0.35	30
5. Machine room	3,040	200	0.63	12
6. Calendar room	5,615	400	0.50	10

* A night photograph of this installation is shown in Fig. 8.

CLOTHING MANUFACTURING.

In clothing manufacturing certain processes have been satisfactorily lighted by mercury-vapor lamps. A large quantity of light, however, is necessary to properly see the texture of the goods, especially in the pressing where one 400-watt lamps is generally placed over each pressing table.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Cutters	448	400	1.72	10
2. Hand sewing	5,400	400	0.74	10
3. Pressing	4,500	400	1.60	10
4. Pressing	1,650	400	0.95	10
5. Pressing	880	400	2.19	10
6. Pressing	2,445	400	1.64	11

POWER HOUSE LIGHTING.

Power house lighting covers the illumination of the boiler rooms and engine and generator rooms. In the boiler rooms gen-

eral illumination is provided for the aisles with small individual lamps placed at the gauge glasses. While in the engine and generator rooms, individual lamps in some cases are used in and under the engines. The amount of illumination is generally not very high.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Boiler room	12,985	200	0.60	18
2. Boiler room	8,945	200	0.64	18
3. Boiler room	12,670	200	0.58	16
4. Boiler room	18,000	400	0.17	40
5. Boiler room	7,065	400	0.27	20
ENGINE AND GENERATOR ROOMS.				
1. Turbine room	20,000	725	0.25	46
2. Turbine room	27,000	725	0.24	85
3. Turbine room	10,500	725	0.21	81
4. Sub-station	4,200	400	0.64	25
5. Turbine room	13,980	400	0.33	40
6. Turbine room*	27,000	400	0.17	18
7. Engine room	10,470	400	0.22	32
8. Turbine room	25,345	200–400	0.49	18–45
9. Engine room	8,100	200	0.24	14
10. Engine room	13,200	400	0.58	30–75

* A night photograph of this installation is shown in Fig. 9.

GLASS MANUFACTURING.

The operations in glass manufacturing which have been successfully lighted by mercury-vapor lamps are all grades of inspection, the grinding and polishing and similar operations of plate glass, machine cutting and engraving of cut glass. The latter and inspection requires extremely good illumination.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Lehr inspection........	384	400	2.00	12
2. Polishing and grinding	11,890	400	0.71	22
3. Polishing and grinding	42,000	725	0.38	36
4. Stripping	11,890	400	0.71	15
5. Laying	7,680	400	1.10	15
6. Final inspection*.......	3,000	400	1.28	10
7. Machine cutting........	10,300	400	0.85	12
8. Engraving	600	400	5.00	12

* A night photograph of this installation is shown in Fig. 10.

SHIPPING AND STORAGE.

Practically all manufacturing plants have shipping and storage departments, and while in a great many cases where there are high

bins mercury-vapor lamps on account of the size may not be available, still in numerous cases they have been successfully used for storage and for shipping and similar departments.

Class of work	Total sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1. Warehouse	14,600	200	0.24	10
2. Shipping platform......	1,000	200	0.96	8
3. Freight house	76,000	200	0.20	8–10
4. Freight house	14,400	200	0.32	8–10
5. Freight house	9,600	200	0.24	10–12
6. Shipping dept.	7,800	400	0.49	12
7. Craneway*	33,600	725	0.25	80

* A night photograph of this installation is shown in Fig. 11.

MOTION PICTURE STUDIOS.

Whether motion picture studios may be termed industrial plants is somewhat open to discussion, but it is in the studio that the first operation in the manufacture of the film is performed, and as mercury-vapor lamps are extensively used for this class of work, data regarding them may be of interest.

As far as is known, there are in the United States about 50 studios using artificial light for the taking of motion pictures. Of these 43 are using mercury-vapor lamps either entirely or in combination with other systems. Nearly all of them use at least one or two large arc lamps to obtain special lighting effects. The data furnished below do not take into account the energy consumed by these arcs.

	Number stages	Watts per lamp	Watts per sq. ft. of floor area illuminated	Height, Feet
1.*	4	400	100.0	8–16
2.	1	725–400	65.0	8–10
3.	1	725–400	47.0	8–15
4.	2	400	128.0	8–14
5.	2	400	100.0	8–15
6.	1	400	83.0	8–12
7.	1	400	99.0	8–13
8.	1	400	104.0	8–13
9.	1	400	89.0	8–12
10.	1	400	85.0	8–12

* A night photograph of this installation is shown in Fig. 12.

MISCELLANEOUS INDUSTRIES.

In addition to the data given in the previous tables, there have been obtained information relative to the lighting of certain operations in other industries which are all grouped under the heading of miscellaneous industries.

	Plant	Operation	Illum'd. sq. ft.	Watts per lamp	Watts per sq. ft.	Height Feet
1.	Rubber	Rubberizing cloth	4,550	200-400	0.46	16
2.	Steel	Rolling mill	24,000	400	0.20	15
3.	Metal fur.	Finishing	9,405	400	0.49	12
4.	Metal boats	"	16,900	400	0.36	14
5.	Hat mfg.	Sizing room	7,240	400	0.64	12
6.	Shoe mfg.	Cutting	870	200-400	3.12	10
7.	Copper refg.	Electrolytic room	86,400	725	0.18	29
8.	Metal plant	Electroplating	8,340	200	1.00	11
9.	Copper refg.	Grind'g and crush'g	4,500	200	0.13	40
10.	"	Concentrating	8,000	200	0.14	12-16
11.	"	Jigs	10,000	200	0.15	18-28
12.	Powder mfg.	Press room	1,200	400	1.00	9½
13.	Sugar plants	Inspection dept.		200	One for ea insp.	8
14.	Ivory plants	Sorting dept.		200	" sorter	8

CONCLUSIONS.

The data furnished in this paper have been the result of practically twelve years use of mercury-vapor lamps in the industrial field. While the figures vary somewhat for the same class of work, it might be said that this condition depends to a certain extent on the state of mind of the different plant managers. Some appreciate the fact that up to a certain limit they cannot have too much light to produce the best results and look upon good lighting as an asset; whereas others feel that they wish to get along with as little light as possible, and feel that light is merely a necessary evil which must be used.

By using the figures given there is no doubt but what the plant engineer of any concern desirous of using mercury-vapor lamps will be able to estimate fairly accurately the amount of light that may be needed for different operations.

In designing a good industrial lighting system, the following points should be borne in mind. Provide an illumination that will not dazzle the eyes of the operatives, one with a low intrinsic brilliancy and with as little glare as possible that will be easy on the eyes of the operatives and thoroughly diffused, all of which

will tend to prevent accidents and safeguard the health of those working under it.

The system of lighting should be installed with the idea of producing the greatest quantity of goods of the best quality, in other words, design the lighting not with the idea of the "proximate" efficiency of the lighting unit, but with the "ultimate" efficiency of the plant.

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DISCUSSION.

MR. R. B. ELY: Several questions have occurred to me in reference to the use of mercury-vapor lamp, particularly where it is used around iron and steel works. There are a great many markings on the iron which indicate the relative positions for placing the various pieces together, etc., and I was wondering whether the red chalk or red paint marks would show distinctly under the light from this lamp. I know there has been some trouble experienced in determining red markings, the red pencil marks on packing cases calling attention to special shipments, for instance. The red might appear black under a mercury-vapor light. Now on an iron surface would the red chalk marks show up at all, or would they appear of a different color?

MR. W. A. D. EVANS (In reply): The red chalk marks would not appear a bright red under the mercury-vapor lamp, but will appear a dark brown. With a little practise, however, one could very easily differentiate. We use the mercury-vapor lamps in our office and, of course, in our ledgers both red and black ink are used to indicate different accounts, and the clerks do not have any difficulty in distinguishing one from the other, and I know the same condition occurs in other cases.

THE PARABOLIC MIRROR.*

BY FRANK A. BENFORD, JR.

Synopsis: The following discussion of the parabolic mirror is divided into two main sections, one devoted to such mirrors with a spherical light source and the other devoted to mirrors reflecting light from a disk source. These two types of sources are ideal cases of incandescent and arc lamps, respectively. Preceding the two main sections a short discussion of a parabolic mirror with a point source is given. In ordinary photometry the fiction of a "point source" is highly useful and may usually be used without question as to its accuracy. However, all present known light sources fall far short of performing as a "point source" when placed at the focal point of a parabolic reflector.

A searchlight, or headlight, consists of a source of light, usually of small area and high brilliancy, placed at the focal point of a parabolic mirror, or some nearly equivalent form of reflector. There is an extremely large number of uses that may be found for an intense beam of light of small angular width. In military and naval service, in all types of navigation, and in nearly every type of land transportation, the searchlight and headlight play a highly important part. There is also a large field for the searchlight in flood lighting and spectacular work. In all of these various types of service the principles of design are the same, and the difference between one searchlight and another is a difference in degree, not in principle.

SYMBOLS.

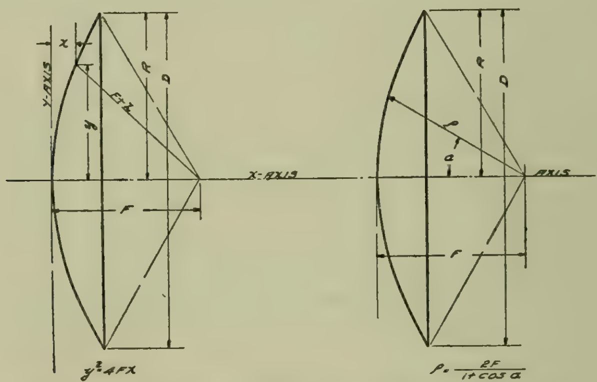
F—focal length of mirror, in inches.
D—diameter of mirror, in inches.
R—radius of mirror, in inches.
r—radius of light source, in inches.
m—coefficient of reflection of mirror.
s—area of light source, in square inches.
I_a—intensity of light source at angle a from axis of mirror, in international candles.
I_B—intensity of beam, in international candles.
B—brilliancy of light source, in candles per square inch.
L—distance from focal point to point in beam, in feet.

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

A—area illuminated, in square feet.
E—illumination on a plane normal to beam, in foot-candles.
Q—light flux, in lumens.
a—angles measured about the focal point of mirror, in degrees.
b—beam angles measured from the axis of mirror, in degrees.
e—angle subtended by the radius of the source at any point on the mirror, in degrees.

PARABOLIC MIRROR AND POINT SOURCE.

In all that is to follow, the mirror is assumed to be ideal in form. The variations that occur in practice represent manufacturing problems and difficulties and need not be considered here.



Figs. 1 and 2.—Parabolic mirror; equation of generating curve.

The parabolic curve from which the parabolic mirror is generated by rotating the curve about its axis has for its equation either

$$y^2 = 4Fx \qquad (1)$$

the rectangular form, see Fig. 1, or

$$\rho = \frac{2F}{1 + \cos a} \qquad (2)$$

the polar form, see Fig. 2.

Using the rectangular form of equation, we have

$$y^2 = 4Fx$$

and the slope of the line drawn tangent to the parabola at point P, Fig, 3, is

$$\frac{dy}{dx} = \frac{2F}{y} = \tan c, \qquad (3)$$

The slope of the normal to the curve at this point is

$$-\frac{dx}{dy} = -\frac{y}{2F} = \tan e \quad \ldots\ldots\ldots\ldots \quad (4)$$

From the figure, light emitted from the focus follows the line OP, and

$$\tan a = \frac{y}{F - x} \quad \ldots\ldots\ldots\ldots\ldots \quad (5)$$

$$a + c + d = 180 \quad \ldots\ldots\ldots\ldots\ldots \quad (6)$$

$$\tan (a + c) = \tan (180 - d) = \tan d \quad \ldots\ldots\ldots \quad (7)$$

and from (3), (5) and (7), we obtain

$$\tan d = -\frac{2F}{y} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

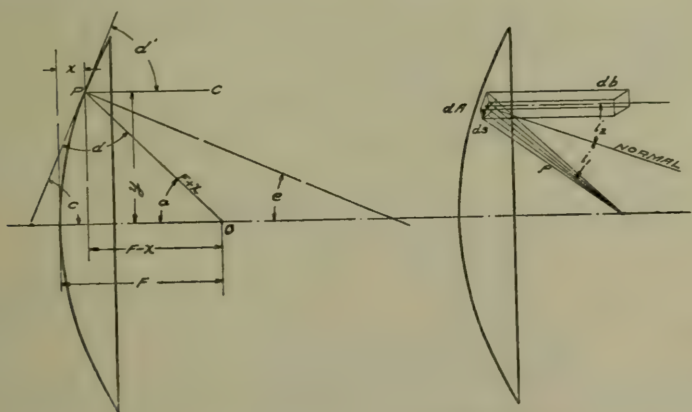
From the law of reflection of light, we have

$$d' = d,$$

and, therefore, as tan c and tan d are numerically equal,

$$d' = c \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

and the reflected ray PC is parallel to the axis.



Figs. 3 and 4.—Parabolic mirror and point source.

A beam of light made up of rays such as PC would form a true cylinder of unvarying diameter. Each ray would pursue an independent path parallel to all the other rays, and hence, the intensities of flux found in any cross section of the beam would be identical with the intensities in all other cross sections. It is

obvious that in this case we may find the flux density or illumination at any point of the beam, but we may not assign any candle intensity to it. The beam has some of the properties of a beam coming from an intense source at an infinite distance. These conditions are as physically impossible as the "point source" that was assumed in the beginning.

It may be shown that the flux intensity in any section of the beam db, Fig. 4, is equal to the flux intensity at a distance ρ from the source before reflection takes place.

Let a small area dA on the surface of the mirror be illuminated from a point source at the focal point. The cone of light striking this area has an angle of incidence i_1, as shown in Fig. 4. The spherical area of this cone at the radius ρ is

$$ds = dA \cos i_1 \text{ square inches} \quad \ldots\ldots\ldots\ldots (10)$$

The right section of the reflected beam has an area

$$db = dA \cos i_2 \text{ square inches} \quad \ldots\ldots\ldots\ldots (11)$$

and as

$$i_1 = i_2 \text{ degrees} \quad \ldots\ldots\ldots\ldots (12)$$

$$db = ds \text{ square inches} \quad \ldots\ldots\ldots\ldots (13)$$

The areas db and ds contain the same quantity of light, ΔQ, and, therefore, the density is the same.

The intensity of radiation at radius ρ is

$$E = \frac{I}{\rho^2} \text{ foot-candles} \quad \ldots\ldots\ldots\ldots (14)$$

$$\begin{aligned} \rho^2 &= y^2 + (F - x)^2, \text{ from Fig. 1.} \\ &= 4Fx + F^2 - 2Fx + x^2 \\ &= F^2 + 2Fx + x^2 = (F + x)^2 \text{ inches}^2 \quad \ldots\ldots (15) \end{aligned}$$

$$E = \frac{I}{(F + x)^2} \text{ foot-candles} \quad \ldots\ldots\ldots\ldots (16)$$

and with a mirror having a coefficient of reflection m the beam intensity is

$$E = \frac{mI}{(F + x)^2} \text{ foot-candles} \quad \ldots\ldots\ldots\ldots (17)$$

In Fig. 5 the beam intensities are plotted for a source having a uniform intensity of one candle in three typical 18-inch (45.7 cm.) mirrors. The angular openings of the mirrors are, measuring from the axis, 60°, 90° and 120°.

PARABOLIC MIRROR AND SPHERICAL SOURCE.

In solving for the beam characteristics of a spherical source in a parabolic mirror, it is necessary to make the assumption that the distance across the mirror is very small in comparison to the distance out along the axis of the beam where the intensities are to be calculated. The effect of distance on the apparent intensity of the beam will be taken up later.

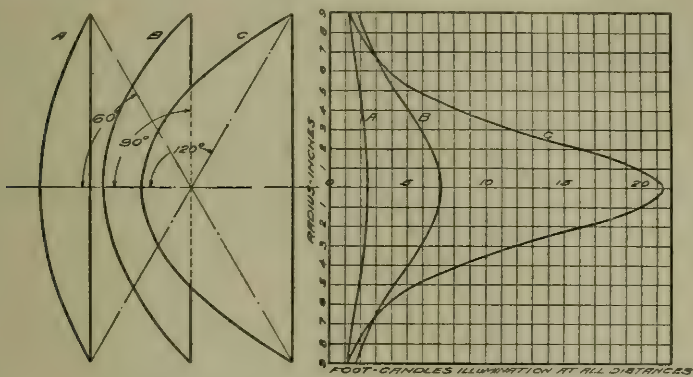


Fig. 5.—Parabolic mirror and point source beam characteristics.

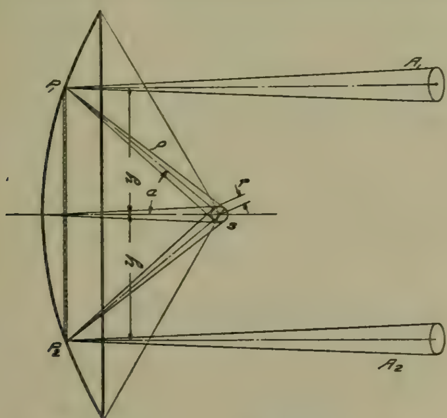


Fig. 6.—Parabolic mirror and spherical source.

In Fig. 6, two small sections of the mirror, P_1 and P_2, reflect two rays which at a considerable distance from the mirror will overlap. If the distance is great enough the areas A_1 and A_2 become very large and the distance $2y$ between their centers may be neglected.

Assume the plane area of a great section of the spherical source to be s square inches, then the areas A_1 and A_2 are found by the proportion

$$\frac{A}{s} = \left(\frac{L}{\rho}\right)^2$$

or

$$A = s\left(\frac{L}{\rho}\right)^2 \text{ square feet} \quad \ldots\ldots\ldots\ldots \quad (18)$$

The shaded section of mirror, Fig. 6, may be considered as a ring of small elements P_1, P_2, etc., all at the same distance ρ from the focus.

The quantity of light reflected from the ring is

$$\Delta Q = 2\pi m I \sin a \,\Delta a \text{ lumens} \quad \ldots\ldots\ldots\ldots \quad (19)$$

I is the intensity of the source, assumed to be equal in all directions, and m is the coefficient of reflection of the mirror.

The illumination from the ring is

$$\Delta E = \frac{\Delta Q}{A}$$

$$= \frac{2\pi m I \sin a \,\Delta a}{s\left(\frac{L}{\rho}\right)^2} \text{ foot-candles} \quad \ldots\ldots \quad (20)$$

From equation (2)

$$\rho = \frac{2F}{1 + \cos a}$$

and

$$\Delta E = \frac{8\pi m I F^2 \sin a \,\Delta a}{sL^2(1 + \cos a)^2}$$

$$E = \frac{8\pi m I F^2}{sL^2} \int_o^{a_1} \frac{\sin a \, da}{(1 + \cos a)^2}$$

$$= \frac{4\pi m I F^2}{sL^2} \tan^2 \tfrac{1}{2} a_1, \text{ foot-candles} \quad \ldots\ldots\ldots \quad (21)$$

This is one form of the equation for the central density of a beam from a spherical source and a parabolic mirror. With a fixed focal length, the intensity varies as the square of the tangent of half the angle a_1, or given a fixed angular opening, the intensity varies as the square of the focal length.

We may write

$$\frac{I}{s} = B \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (22)$$

the brilliancy in candles per square inch, then (21) becomes

$$E = \frac{4\pi m BF^2}{L^2} \tan^2 \tfrac{1}{2}a_1 \text{ foot-candles} \ldots (23)$$

This equation is particularly valuable as it shows that the intensity at the center of the beam depends upon the *brilliancy* of the light source and is independent of the size of the luminous sphere. This has an important bearing on the design of incandescent filaments for searchlights, etc.

The above equation may be written

$$E = \frac{\pi m BR^2}{L^2} \text{ foot-candles} \ldots\ldots\ldots\ldots (24)$$

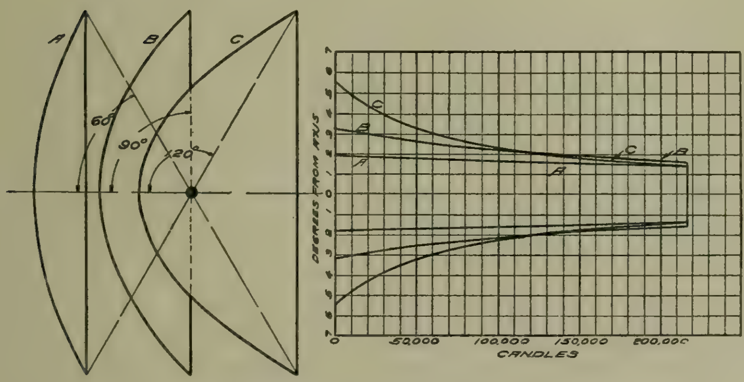


Fig. 7.—Parabolic mirror and spherical source beam characteristics.

The focal length does not enter into equation (24), and this brings out the highly interesting fact that all parabolic mirrors having the same diameter should give the same illumination at points on the axis. The difference in action between a shallow and deep reflector is shown in Fig. 7, where the beam intensities of three 18 in. (45.7 cm.) mirrors of different focal lengths are plotted. The same source, having a uniform brilliancy of 1,000 candles per square inch and a diameter of 0.5 in. (1.27 cm.), is used in all three mirrors.

The two latter equations, by a simple transformation, may be used to calculate the candle intensities on the axis.

$$I_B = 4\pi m BF^2 \tan^2 \tfrac{1}{2} a_1 \text{ candles} \ldots\ldots\ldots \quad (25)$$

and

$$I_B = \pi R^2 B m \quad \text{candles} \ldots\ldots\ldots\ldots\ldots\ldots \quad (26)$$

The last equation states that the *intensity of a searchlight beam is equal to the product of the brilliancy of the source, the plane area of the mirror and the coefficient of reflection.*

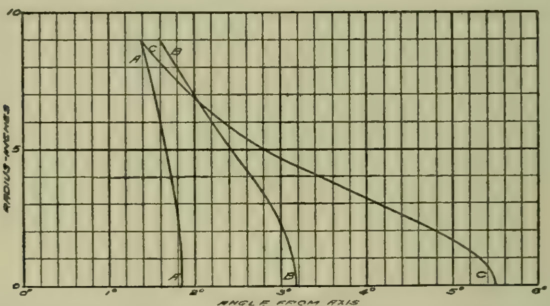


Fig. 8.—Parabolic mirror and spherical source. Angular width of beam from different radii on mirror.

The intensities at points not on the axis of the beam may be found by the use of (26) and the following relations:

The apparent angular radius of the source viewed from the central point on the mirror is

$$e_o = \tan^{-1} \frac{r}{\rho_o} = \tan^{-1} \frac{r}{F} \text{ degrees} \ldots\ldots\ldots \quad (27)$$

At other points on the mirror we have as a good approximation

$$e = e_o \frac{\rho_o}{\rho} \text{ degrees} \ldots\ldots\ldots\ldots\ldots\ldots \quad (28)$$

The light incident upon the center of the mirror has the greatest spread and is distributed throughout the entire beam. The light from the edges of the mirror is concentrated within a smaller angle and this light forms the center of the beam. By noticing the angle of spread at different parts of the mirror, the area covered by any section may be readily obtained.

Values of (28) for the three mirrors of Fig. 7 are given in Fig. 8. The angle of spread of the beam, b, is equal to the angle subtended by the source, e.

The curves in Fig. 8 may be interpretated as follows: Suppose an observer to stand at a considerable distance from mirror C and slowly approach the axis of the beam. When he reaches a point 5.5° from the axis the center of the mirror will become visible. At a point 5° from the axis the luminous spot will be 1.7 in. in radius. The luminous area will continue to grow until the observer reaches a point 1.38° from the axis when the entire mirror will be covered. From this point to a similar point 1.38° on the opposite side of the axis, the area and the total apparent beam intensity will remain constant, and from this point the luminous area will appear to decrease until the observer steps out of the beam at 5.5°.

It is rather difficult to actually observe the action of the luminous spot on the mirror as outlined above on account of the great distance at which the observer must stand. At an insufficient distance the mirror will first appear luminous at the center and the edge nearest the observer. These two spots will merge and form an oval area that gradually approaches the size of the mirror as the observer comes up to the axis of the beam.

Under ideal conditions the area of the mirror that is active is found from (28), and this area substituted in (26) gives the beam intensity at the beam angle *b*.

The illumination curves in Fig. 5 seem to differ in practically every respect from the beam intensity curves in Fig. 7. If foot-candle readings are taken very close to the surface of the mirror of Fig. 7 the illumination curves will be found to approach the point source curves in form. The two sets of curves represent the conditions at opposite ends of the beam. Between these two extremes of distance, zero and infinity, the beam undergoes a gradual transformation, and it is in this region of transformation that our practical interest is centered.

When tests are made to determine the beam characteristics of a searchlight one of the first questions that comes up is the question of the proper testing radius. It is well known that the apparent intensity and angular spread of the beam may vary at different distances, and that tests made at relatively short distances are unreliable.

One of the most desirable conditions of a searchlight test is

that the data may be used to calculate illumination at various distances by making use of the inverse square law.

The intensity of the beam has been shown to be proportional to the area of the mirror, that is, with a given source, all parabolic mirrors have the same brilliancy. Equation (26) may be rewritten

$$\frac{I_B}{\pi R^2} = mB \text{ candles per square inch} \quad \ldots\ldots\ldots \quad (29)$$

The beam candles divided by the area of the mirror gives mirror brilliancy

$$B_m = mB \text{ candles per square inch} \quad \ldots\ldots\ldots \quad (30)$$

and it is at once evident that the beam has a maximum and constant candle intensity at all points receiving light from the entire mirror.

Fig. 9.—Parabolic mirror and spherical source. Law of inverse squares.

Once the intensity reaches a constant value the inverse square law may be used to calculate illumination at other distances, within what is called the inverse square region in Fig. 9. The boundaries of this region are formed by the rays from the extreme edge of the mirror.

The angle which the boundaries make with the axis may be found from equation (28) or calculated directly.

$$b_1 = \tan^{-1} \frac{r}{\rho_1} \text{ degrees} \quad \ldots\ldots\ldots\ldots \quad (31)$$

where ρ_1 is the distance from the focus to the edge of the mirror, and the distance at which these boundaries cross the axis is

$$L_o = \frac{R}{12} \cot b_1 \text{ feet} \ldots\ldots\ldots\ldots \quad (32)$$

The following form, which is often more convenient, may be used:

$$L_o = \frac{R\left(F + \frac{R^2}{4F}\right)}{12r} \text{ feet} \ldots\ldots\ldots\ldots\ldots (33)$$

The way in which the centers of the beams from the three 18 in. mirrors approach the maximum intensity is shown in Fig. 10. These curves were determined by giving R various values, and solving (33) for the distance L_0 at which the maximum beam candles would be obtained, and with the same value of R solving (26) for the intensity. If, in place of 18 in. mirrors, we had larger mirrors of the same focal lengths, the points at

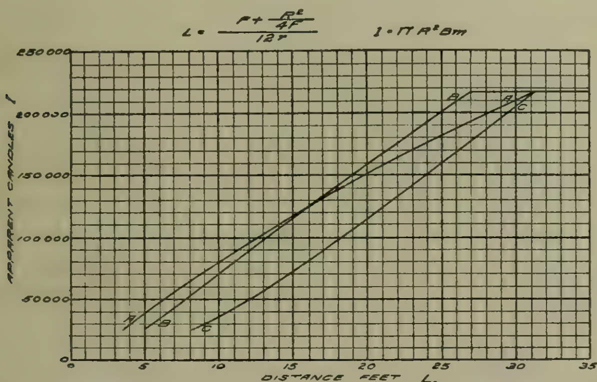


Fig. 10.—Parabolic mirror and spherical source. Apparent candles at points on axis of beam.

which the beams come to full intensity could be found by extending the curves of Fig. 10. An increase in diameter will not affect the axis intensity at points less than L_0 because the added zone of mirror will reflect a beam from points farther removed from the axis and having a smaller angle of divergence, and hence, this added part of the beam will reach the axis at points beyond L_0 for the 18 in. mirrors.

It can be shown that there is considerable freedom of movement allowed the light source without changing the central beam intensity. This intensity has been shown to depend directly upon the brilliancy of the source, and from this we could infer without further proof that the size and shape of the source affects only

the width and side intensities of the beam. The light on the axis comes from those rays of the source that pass through the focal point. It follows that the source may have any size, shape or position whatever, without changing the central beam intensity, providing only that every line from the mirror through the focus will touch the light source.

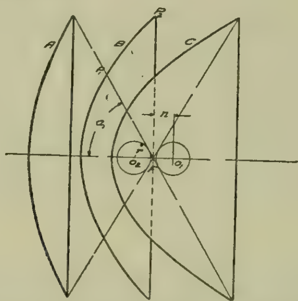


Fig. 11.—Parabolic mirror and spherical source. Freedom of movement of source.

In Fig. 11 the sphere, which is the source of light, is shown in two positions, O_1 and O_2. An inspection of this figure will show that a line from any part of mirror A through F will touch the source in either position, and in all intermediate positions. The allowable movement either way from the focus is then

$$n = r \sec a_1 \text{ inches} \quad \ldots\ldots\ldots\ldots\ldots \quad (34)$$

As the source is moved from O_1 to O_2 the width and shape of the intensity curve will change, but the intensity on the axis will not change. The point at which the inverse square region begins will also shift as the source moves, being closest when the source is at the greatest distance from the mirror.

With the source in positions O_1 or O_2, there will be a zone of mirror B between P_1 and P_2 that will not be active in reflecting light to the axis. With this mirror, and the deeper mirror C, the source can be moved only through its own radius,

or
$$n = r \text{ inches} \ldots\ldots\ldots\ldots\ldots\ldots \quad (35)$$

PARABOLIC MIRROR AND DISK SOURCE.

A disk, placed so that its luminous side is at the focal point and facing the mirror, is the ideal case of the carbon arc. The intensity on the axis of the beam is

$$I_B = \pi R^2 B m \text{ candles} \quad \ldots\ldots\ldots\ldots\ldots \quad (36)$$

The proof of this is almost identical with that given for a spherical source and will not be repeated. For points not on the axis the line of reasoning is not so simple, however, because the beam from any small section of the mirror is elliptical in section and the summation of these elliptical elements leads to complicated mathematical forms. This is not a serious matter, however, as the chief interest of an arc searchlight attaches principally to the central beam intensity.

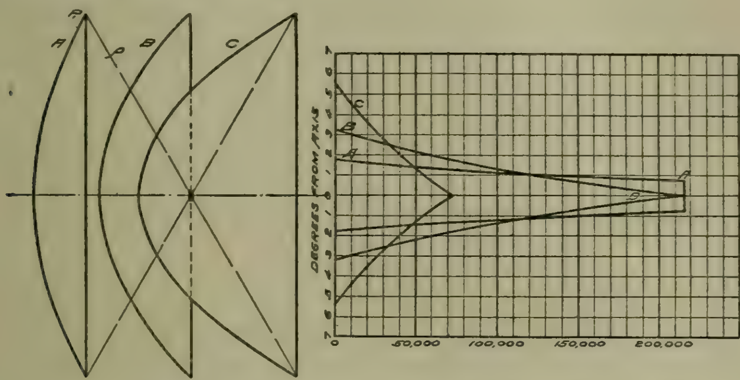


Fig. 12.—Parabolic mirror and desk source. Beam characteristics. (Slopes approximated).

The width of the crest of the intensity curve is determined by the angle subtended by the source from a point on the edge of the mirror. From the point P_1, Fig. 12, the disk appears to be an ellipse having a major axis r, and a minor axis $r \cos a_1$. The cross section of the beam from this element is an ellipse having the same proportions.

The angular half-width of the flat crest of the curve is

$$b_1 = \tan^{-1} \frac{r \cos a_1}{\rho_1} \text{ degrees} \ldots\ldots\ldots\ldots \quad (37)$$

or

$$b_1 = \tan^{-1} \frac{r \cos a_1}{F + \frac{R^2}{4F}} \text{ degrees} \ldots\ldots\ldots\ldots \quad (38)$$

It has been assumed that the disk is luminous on one side only. The part of mirror C between 90° and 120° is not active. The radius R in equations (36) and (38) must in this case be

$$R = \frac{2F}{1 - \cos 90°} = 2F \text{ inches} \ldots\ldots\ldots \quad (39)$$

The width of the crest for mirrors B and C is zero. This is evident both from the above expressions for e and from the fact that the source appears to be a line when viewed from an angle of 90°. The overlapping line beams will give full intensity only at the common crossing point.

The maximum width of the beam is

$$b_o = \tan^{-1} \frac{r}{\rho_o} \text{ degrees} \ldots\ldots\ldots\ldots\ldots (40)$$

or

$$b_o = \tan^{-1} \frac{r}{F} \text{ degrees} \ldots\ldots\ldots\ldots\ldots (41)$$

The brightness of the mirror is as before

$$B_m = mB \text{ candles per square inch} \ldots\ldots\ldots (42)$$

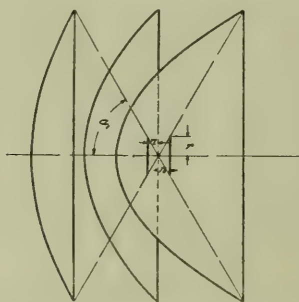


Fig. 13.—Parabolic mirror and desk source. Freedom of movement of source.

The boundaries of the inverse square region make an angle

$$b_1 = \tan^{-1} \frac{r \cos a_1}{\rho_1} \text{ degrees} \ldots\ldots\ldots\ldots (43)$$

or

$$b_1 = \tan^{-1} \frac{r \cos a_1}{F + \frac{R^2}{4F}} \text{ degrees} \ldots\ldots\ldots\ldots (44)$$

with the axis.

The distance at which these boundaries meet is

$$L_o = \frac{R}{12} \cot b_1 \text{ feet} \ldots\ldots\ldots\ldots\ldots\ldots (45)$$

or

$$L_o = \frac{R\left(F + \frac{R^2}{4F}\right)}{12\, r \cos a_1} \text{ feet} \ldots\ldots\ldots\ldots (46)$$

Mirrors having an angle of 90° or over do not have an inverse square region for the rays from the edge of the mirror are parallel and do not meet.

The degree of freedom allowed a disk source is

$$n = r \cos a_1 \text{ inches} \quad \ldots\ldots\ldots\ldots\ldots \quad (47)$$

either way from the focus. See Fig. 13. The movement for a 90° mirror is zero.

The beam characteristic at the surface of the mirror does not follow the point source characteristic developed in the first section. The intensity of radiation at angle a is

$$I_a = I_o \cos a \text{ candles} \quad \ldots\ldots\ldots\ldots\ldots \quad (48)$$

and the foot-candle curve close to the mirror may be found from the equation

$$E = \frac{m I_o \cos a}{(F + x)^2} \text{ foot-candles} \quad \ldots\ldots\ldots\ldots \quad (49)$$

DISCUSSION.

MR. J. L. MINICK: Searchlights, and in fact all forms of light units giving approximately parallel rays of light, are receiving considerable attention at the present time and this paper will undoubtedly be of great value in solving many of the problems incidental to this class of lighting.

During the past few years about two thirds of the states and territories have passed laws requiring the use of locomotive headlights of much higher beam candlepowers than are in common use to-day. The requirements of these laws are usually very indefinite due in some degree at least to the fact that they have been prepared by persons having little or no technical knowledge along lighting lines. In some instances the candlepower or wattage of the lamp without reflector is the principal requirement; in others the diameter of the reflector only is given; in still others the distance at which an object can be seen is specified, while the speed of the train, weather conditions, color of background, etc., are not even referred to.

The railroads have been faithfully trying to solve this problem and papers of this kind will be of material assistance in this connection. The principal objections to the laws now existing are, as stated above, their requirements are very vague and in-

definite and the requirements of adjoining states usually differ from each other, so that one kind of headlight is required in one state and another kind in another state.

I am not prepared to discuss the technical features of Mr. Benford's paper to any great extent as my work has generally been along slightly different lines. I have done some work, however, that checks closely with Mr. Benford's work.

Mr. Benford states that in the application of the law of inverse squares, the distance is measured from the reflector. I presume the focal center is the point from which it is intended that this measurement is to be made. I have discussed this question with several authorities on parabolic reflectors and semaphore lenses and I am told that in the case of the parabolic reflector the measurement should be made from the center of gravity of the longitudinal section of the reflector which will be found on the axis of the reflector at a distance from the front of the reflector equal to one third the total depth of the reflector. In the case of semaphore and inverted semaphore type lenses the distance should be measured from the flat surface of the lens.

I should like to see some investigation of lenses of the above described types for headlight service. They can be readily cleaned, they require no polishing and on the whole are much more desirable for this class of service than are metal reflectors. The polishing of metal reflectors very quickly destroys their reflecting surfaces, making it necessary to continually replate them.

Dr. C. E. K. Mees: The beam brightness with the parabolic mirror is the brightness of the source multiplied by the reflecting power or transmission coefficient of the lens or mirror involved. That being so, since the road brightness is as the candlepower of the source, it is obvious that what is required is to produce as large a source as possible. The remedy in fact, for glare in headlights is fairly simple, in that if one produces a large source—it must be remembered that in an automobile headlight a very long beam is not required—on ccan produce a large road brightness with a comparatively small glare. Unfortunately the tendency in automobile headlights is toward the development of extremely bright, concentrated sources as shown by the production of

6-volt lamps of as much as 72 candlepower, all concentrated into an extremely small spherical filament. When you start to apply the remedy to your own headlight, the practical difficulty is, how to do it? No ground glass at present made and no opal glass has a sufficiently high diffusing coefficient to diffuse the modern tungsten lamp. What is needed is a globe for a lamp, since the automobile headlight has no medium to carry a diffusing screen, a globe which shall be sufficiently diffusing to produce an evenly diffusing surface for the high power lamps used. One can get a wide beam with as little as a hundredth or perhaps a thousandth of the glare now existing, and still get the total illumination, because a driver wants to clearly see the sides of the road; so it seems to me that we must look to the lamp makers to produce such a diffusing globe for their high candlepower automobile lamps, and then we can bring pressure to bear on municipal authorities to compel the adoption of diffusing globes on automobile headlights.

MR. J. R. CRAVATH: There seems to be considerable misconception about the real problem to be met in the case of automobile headlights, in reducing the blinding effect. Replacing the clear glass of the headlight by a diffusing glass, reduces the maximum effective candlepower of the beam many hundreds of times; in other words, it spreads out the beam very nice for illuminating the weeds alongside the roadway, but most drivers object to it for country road driving as not throwing enough light far ahead. I presume we have all thought of directing the light so that it will be confined to the surface of the roadway and not into the eyes of approaching drivers. But the practical difficulty is that road inequalities will raise the beam in many cases, and furthermore, it is very difficult to design reflectors and place lamps accurately enough in practise so that there will not be sufficient spread in the beam to catch the opposing vehicle driver in the eye. The practical way out of it seems to be to require all the powerful headlights to be turned off when on lighted city streets and go only with marking lights, which is entirely practicable, and is required in some cities. Most of the city ordinances on this point are very indefinite. The city of Chicago prohibits a blinding, dazzling or confusing light but does not define what such a

light is. I found upon inquiry at the municipal bureau that is established for that purpose, that it is a light that a certain committee of three looks at and decides to be such. (Laughter.)

Dr. E. P. Hyde: I recall some years ago that a committee of the National Electric Light Association presented a report on street lighting, and I think the aspect of the report that impressed most of us most strongly was the apparent indecision regarding the desiderata of street lighting. It is rather difficult to formulate specifications for street lighting when there is no agreement on the requirements that are to be met by the specified installation, and it has seemed to me for sometime that the same condition exists regarding automobile lighting and the question of glare,—the desiderata which are to be met in designing a proper automobile lighting scheme are not definitely agreed upon. We are impressed more with the case when we hear, as we have heard this morning, more or less divergent views regarding the matter. I think that on the one hand lamp makers and the makers of the automobile headlights themselves have been endeavoring to get as nearly as possible the full value of a parabolic reflector by having a point source and keeping the light cone narrow. On the other hand, Dr. Mees suggests that the great difficulty with it is the fact that there is a narrow light cone. Now those two views are diametrically opposite and the question arises as to just what we do want in the way of illumination by automobile headlights. I think that this Society should take some action in the matter. The question of automobile headlights is one of the livest questions of the day, and I do not know any body in the country to whom the problem should be presented for consideration and action, other than the Illuminating Engineering Society. I should like to recommend—I don't want to put it in the form of a motion—but I should like to recommend that this Society take some action whereby a consideration of this question is definitely undertaken either by some of the existing committees or by some committee formed for the purpose in order that the Society may, if possible, arrive at some conclusions which can be suggested to those who desire to know them and may, in a way, serve as a basis for specifications for automobile headlights, with

the hope that in time the municipalities and counties may adopt these specifications in order that there may be a uniformity throughout the country and in any one city the specifications may be such that an automobile driver may be able to know with certain positiveness that his headlight conforms to the requirements and not be subject to the vagaries of committees of three or any one of the committee of three who may happen to be the victim in the case. With regard to the problem itself, I think that we still are far from knowing the most important elements that enter into producing what we term a glare. I know that it is frequently considered that brightness of the source itself is the principal element, and possibly it is. I would gather from Mr. Cravath's remarks that he thinks that the size of the searchlight in some way affects the brightness. As I see it, if the mirror is a true parabola and if the light source a point source or approximately a point source, the brightness is not affected by the size of the parabolic mirror; it is the same whether you have a large or a small parabolic mirror, so long as you have a parabolic mirror. I think there is another element, however, besides brightness which determines glare, and I believe that each of you could convince himself of it if you perform a rather simple experiment. I think you will find that the glaring effect, considering the contrast between the source at which you are looking and the surroundings to be the same in each case—because of course contrast is a very important element—is determined not only by the brightness of the source but by the total flux of light. I remember some years ago we performed in our laboratory a very simple experiment; we set up a Nernst glower and a condensing lens in such a way that the image of the glower was formed on the cornea. The lens was seen to be filled with light. You did not change the brightness of the source by changing the aperture of the lens, but you could change tremendously the glaring effect by changing the effective size of the lens which changed the amount of light coming into the eye. I think you will find that the two elements enter; there may be other elements which enter, but it seems to me we should undertake to determine in this Society, in some rather definite way, (1) what the elements are that produce the glare and how to avoid them, and (2) what the desiderata in automobile head-

lights are, and endeavor to draw up some specifications by which these desiderata may be met.

Mr. L. C. Porter: Taking up the question of the spread of the beam, it is obvious that for headlight work, for example, a very narrow pencil of light is not satisfactory. That brings in the question of how you are going to determine the spread of the beam; in other words, where is the edge of the beam? What figure can you take? If you had a theoretical point source, you could have a sharp edge beam, but with the sources which are practical—the arc crater and especially the incandescent lamp filament—the beam does not have a sharp edge.

In specifying a headlight there must be some method used to take into account not only the maximum candlepower of the headlight, but also the spread, and I should like to ask Mr. Benford if he has any suggestions as to how he would determine the edge of the beam. For practical manufacturing we must have a method of rating headlights which takes into consideration the spread, the average intensity across this spread, as well as the pick-up distance. I should like to see the valuable theory in this paper supplemented by some of the practical problems which must enter in the manufacture, testing and use of searchlights.

The incandescent lamp is having a very widely increased application to headlight service. It is possible now, with six-volt lamps of about 150 candlepower (a standard lamp) to get over 900,000 beam candlepower from a 20-inch parabolic mirror, and many such headlights are now in service. With a little more powerful lamp one is able to obtain considerably over a million in beam candlepower. Such beams are applicable to navigation service, and many other classes of work which do not require extremely high candlepower beams.

On the eleventh page, Mr. Benford gives a formula which shows the distance at which one can begin to measure beam candlepower. In practise you can generally obtain more accurate results by using considerably greater distances than the minimum which the formula shows. At this distance, the intensity is so high that it is difficult to measure it with a photometer, but if you go off several hundred feet you can get photometric readings fairly accurate.

In regard to the question of automobile headlights, in New Jersey there is a rule forbidding the use of headlights which produce glare, and a commissioner passes upon devices which eliminate glare. It may be of interest to you to know of some of these devices which have been approved. One of the first schemes was to dip the upper two thirds of the front glass of the headlight in either an opal or an amber dip, amber being recommended. As has been pointed out, that has the disadvantage of largely reducing the illumination on the road. Another method is to put a dip on the lamp itself, this dip generally being opal and taking a form which will cover the lower half of the bulb and the direct rays from the filament itself. Another method which has been approved is to paint or paste paper on the lower half of the parabolic reflector, *i. e.*, dull it by some method. Still another one is the use of a Venetian blind effect across the front of the headlight, the idea of this being that it will protect the pedestrian's eyes but will let the light go down on the road. Another method in common use is a small candlepower lamp in the top of the reflector. Still another one is the use of resistance to simply cut down the candlepower of the light for city driving. In New Jersey such a device is not acceptable; the rule states that no device will be acceptable which is within the control of the driver. That seems to be a little unreasonable. For city use, a powerful beam is not required because the cars move slowly and the driver has the street lamps to help out, and either the method of reducing the candlepower of the lamp by resistance or turning on a small lamp and extinguishing the main lamp gives perfectly satisfactory illumination. In the country one should naturally be able to use a more powerful beam, because there, one drives faster. As Mr. Cravath has pointed out, it is not a very simple matter to direct the beam down on the road because the distance at which a driver wants to see the road varies with the speed of the car, and at the same time the driver must be able to see down on the immediate foreground. It is very difficult to drive with a bright spot of light several hundred feet ahead and darkness in the immediate foreground of your car. Another method which has been used to some extent is the use of lenses to more or less accomplish this, and I believe that Dr. Gage is going to say something on that subject.

I thoroughly agree with Dr. Hyde that there should be further research on this question and that the Illuminating Engineering Society should cooperate with those having to do with the automobile industry in this work. I do not feel that the glare reducing device should be a part of the incandescent lamp itself. The lamp should be as simple as possible and applicable to any kind or type of headlight. The sockets in many headlight equipments are not adjustable; therefore, a glare reducing device if put on the lamp itself might be satisfactory for one car and not for another.

One method which can be easily applied to the lamp, though, and which has been applied to some of the high candlepower tungsten lamps is to all-frost the bulb having a concentrated filament. With the all-frosted bulb there is enough of the main beam left to show light at a distance, and yet the all-frosted bulb gives considerable light in the foreground and reduces the glare somewhat.

I have felt that good results might be accomplished by the use of polarized light either having two sets of tourmaline crystals for the front glass of the headlight, or one set on the headlight and the other set used by the driver for goggles.

Dr. H. P. Gage: I should like to add something to Mr. Benford's paper on the theoretical calculation of the intensity of the beam as obtained by the use of semaphore lenses. The results come out very similar to those of the parabolic reflector. We start out with a certain intrinsic brilliancy of the source, which we can call I or S. The lens or mirror re-directs the light from this source into a practically parallel beam. All actual sources which it is necessary to consider are not point sources, but extended sources; consequently, looking at this lens from in front, at any reasonable distance for which the lens is to be used, the apparent size of the source is magnified so that it covers the entire front surface of the lens. The simple method of calculating the candlepower in this case is to multiply the intrinsic brilliancy of the source by the area of the lens, and by some factor which in my experiments I call area efficiency, and which Mr. Benford calls reflective efficiency. As the lens is seen from the front, one gets an appearance of a solid disk of light inter-

rupted by dark rings. The average intrinsic brilliancy of the lens is reduced by those dark rings as well as by the reflection losses and absorption losses of the lens itself.

Regarding the comment as to where, when a lens is set up, the distance from the lens should be measured—the distance is measured from the edge of the lens, because the lens appear as a luminous disk of light. At the Corning Glass Works we specify the projected beam as follows: First, the apparent candlepower of the center of the beam, calling that the beam intensity. For the spread of the beam, we take the angle between the two directions where the intensity has fallen off to 50 per cent. of the axial intensity and call it the spread of 50 per cent. intensity. For signal purposes, the angle between the directions where the beam shows about 1 candlepower is called the extreme spread. The spread of 50 per cent. intensity would, I think, be a good measure to take for the spread of beam with the different headlight reflectors.

I should like to make a few comments on the parabolic reflector as used as an automobile headlight and some of the devices for reducing glare. Frosting the upper two thirds of the reflector has been suggested. Placing a small source at the exact focus of the parabola, results in a perfectly parallel beam of light. Any light source available is an extended source and generally approximately spherical. The angle subtended at the center of the reflector extended forward gives the spread from the apex of the parabola, making the small spot in the center referred to by Mr. Benford. At the extreme edge of the parabola, the angle subtended by the source is very small; consequently there is a very small spread; that is, each zone of the reflector has a different spread from every other zone, the outside being the smallest. If the person setting up an automobile headlight focuses the source inside the focus, the beam from the lower clear part of the parabola is directed downward toward the road exactly the same as though the whole headlight were directed down. If, on the other hand, the lamp is set in front of the focus the beam from the lower part of the parabola is directed upward right into the eyes of an approaching automobile driver and no illumination of the road in front of the lamp results. If

the Illuminating Engineering Society decides on specifications, this device should be considered practically worthless. I have had some slight experience driving an automobile against glaring headlights, and perhaps what I can say will appeal to a number of others as the result of actual experience. In meeting an approaching automobile, the glare seems to me proportional to the intensity of the light; that is, the candlepower of the approaching light, and, as Dr. Hyde mentioned, the glare depends on the square root of the candlepower rather than on whether the headlight is of large or small diameter; *i. e.,* it is the question of candlepower rather than of intrinsic brilliancy. The important criterion of glare is not the discomfort to the eyes of the driver, but it is the question whether the driver can see beyond the light. Some devices will reduce the discomfort of the opposing light, but do not increase the visibility beyond that light. That question is coming up, and my suggestion of the solution would be something as follows: Set up a large white screen, perhaps larger than this blackboard, with a hole in the center through which can be seen the headlight to be tested; around the opening paste or write on test letters such as are used by occulists, twice the size usually employed for the given distance. If the headlight is to be observed at 50 ft. (15.24 m.), use the size for 100 ft. The test is made by illuminating moderately the test letters and observing the conditions under which these letters can be read and how close to the axis of the headlight they can be read.

NORMAN MACBETH: My experience has been that the glare effect of headlights depends more largely upon the extent of the retina covered by an after image and the period of recovery which is, of course, largely dependent upon the extent and nature of the retinal burn. The solution of this problem lies in the control of the light as against the more generally practised methods of absorbing the uncontrolled and misdirected light. I have driven many hundred miles making observations with headlights, particularly those where the beams are confined within a very narrow angle—where a very narrow beam was directed forward and downward along the road. The parabolic reflector, the kind we experimented with, was shallow and intercepted only

a third of the light flux generated by the lamp, and there was considerable direct light from the lamp around the front of the machine. I have driven in machines equipped with headlights having proper reflectors and there is absolutely no light within a safe distance of the eyes of approaching drivers.

Three or four years ago, when the amber glasses came out, the manufacturers said, "The solution of the headlight glare is to wear a pair of amber glasses." My personal opinion after road tests, was that the amber glasses resulted in about the same effect as if you closed your eyes when you were approaching a headlight and opened them immediately after it had passed, thus eliminating a burning of the retina and enabling you immediately to see the road again.

There has been a great deal of foolishness attached to this headlight proposition. One manufacturer, for instance, uses a hemispherical globe on the front of the lamp, etching all but a small clear spot below the center and makes the claim that "this headlight is without glare because of the illuminated background surrounding the high intensity spot." The illuminated background being 10 in. (25.4 mm.) in diameter, subtends but a slightly wider angle and in area is far from being a background. The real trouble is that headlights are part of a car equipment. Manufacturers of automobiles to-day are putting out their cars by the thousands and tens of thousands and I know manufacturers who have supplied devices for automobiles one year and lost that business the following year because their devices cost 5 cents per car more than some other available device, and on fifty thousand cars the saving was reckoned. The reflector for automobile headlights, as used to-day, cost 60 to 80 cents. There was none of this difficulty in the old type of lamps using acetylene, not because they were gas lamps but because they used mangin mirrors.

I made a test a short time ago with properly designed, well made metal reflectors. I had two of these reflectors freshly plated, polished and put in good condition; then I took one of them and with a piece of fine emery cloth, carefully scratched the surface of the reflector. This was just the cleaning process exaggerated and that reflector had a light distribution as wide as

one would secure with a China dinner plate. The other reflector confined the beam within 3° in a similar manner to a good ground and polished mirrored glass reflector. Many hours of observation with headlights having reflectors good and bad have convinced me that a well made properly ground to shape, mirrored glass reflector with a beam within 2° or 3° will meet all the just requirements—that light should not be directed higher than 4 or 5 feet above the ground in order to protect both the driver and those approaching a car so equipped. From one pair of such reflectors I obtained a beam of 68,000 candlepower with 24-candlepower lamps. The reflectors were shallow and intercepted less than half the light generated.

A very simple and effective method was adopted for city driving. The lamp sockets were attached to a sleeve with a hinge controlled by magnets in such a manner that by pressing a convenient button the lamp was moved up about an inch and out of focus with the result that a large pear-shaped image of the lamp filament was projected onto the pavement just in front of the machine and forward for about 40 feet. My conclusion has been that the solution of the headlight glare proposition is simply a matter of the control of light, which is not difficult unless one is required to do it for an amount not exceeding one dollar per lamp.

Mr. W. R. Mott: The headlights on automobiles are, most of them, stationary, and it is perfectly possible now, with the development of headlight turning apparatus, to turn the headlight with the wheels. I have ridden in automobiles thus equipped and noticed a great improvement in the lighting.

Dr. P. G. Nutting: I do not wish to take the time of the Society with any further discussion, but I wish to make the announcement that this whole subject is adequately treated, I think, in the report on automobile headlights of the Committee on Glare.* In this report we have discussed the subject from elementary optics to model ordinances. A great deal of discussion would have been saved if this report had been presented here. Nearly all the questions raised this morning are answered in that report.

* This report is to appear in the next issue of the Transactions.

MR. F. A. BENFORD (In reply): Mr. Minick brought up the question of measuring the zero point along the beam. I have taken the zero point at the source. Actually the zero point should be in the edge of the plane of the opening of the mirror. This applies both to a lens and to any type of reflector. The difference between the edge of the plane of the opening and the source is ordinarily very small and may be neglected.

Dr. Mees' suggestion as to frosting the bulb was answered by Mr. Cravath's saying that the intensity of the beam would be reduced in the same proportion as the intensity of the parent source.

DR. MEES: I suggested the frosting of the bulb and Mr. Cravath was talking about the frosting of the lens.

MR. BENFORD: It works out somewhat the same, though.

DR. MEES: Not at all.

MR. BENFORD: In reducing the candlepower in the center, I mean.

DR. MEES: Not in distribution.

MR. BENFORD: Mr. Porter brought up the question of the edge of the beam with a view of establishing some percentage of intensity which may be called the edge. That may be done for certain classes of work and yet would not be a good thing as a rule. Take the automobile headlight, as an example, the intensity of one candlepower at an angle of 45° downward from the lens will produce more illumination, on the average, than 10,000 candlepower in the center of the beam, because of the great distance at which the center will strike the road and the high angle of incidence; so if one puts an arbitrary edge to the beam at 10 per cent. of the center intensity, one will be losing much of the effective light.

ULTRA-VIOLET RADIATION AND THE EYE.*

BY W. E. BURGE.

Synopsis: Transparent, free-swimming, unicellular organisms, paramecia were exposed to the radiation from a quartz mercury burner and observed under the microscope during the exposure. The organisms became more and more opaque during the exposure and were dead after 30 minutes. The conclusion is drawn that ultra-violet radiation kills living cells by coagulating the protein of the cells, as is the case when they are heated to 100° C.

A square of glass was covered with a thin film of egg white and permitted to dry. A piece of cardboard with a circular area cut from the center was fitted over the transparent film. This preparation was placed 10 cm. from a quartz mercury burner and allowed to remain for 30 hours. Thus the circular area of egg white was exposed to the radiation while that under the cardboard was not. At the end of the 30 hours the cardboard was removed. No difference could be seen between the exposed and unexposed parts of the film of egg white. The preparation was immersed in 0.1 per cent. calcium chloride for 10 minutes. The exposed circular area became an opaque coagulum while the unexposed part remained transparent. The conclusion is drawn that ultra-violet radiation coagulates protein by changing it in such a way that certain salts such as those of calcium can combine with it to form a coagulum.

The eyes of one batch of frogs living partially immersed in 0.1 per cent. sodium silicate were exposed to the radiation from a quartz mercury burner. The eyes of another batch living partially immersed in tap water were also exposed. Those living in the silicate developed very severe anterior eye trouble, while those living in tap water developed it very slightly. The eyes of fish living in 0.1 per cent. sodium silicate were exposed to the radiation from a quartz mercury burner for the same length of time as those living in tap water. Those in the silicate solution developed cataract, while those in tap water did not. The unmoistened human skin was exposed to the sunlight as well as skin moistened with water rich in calcium salts. The skin that was moistened sunburned much more quickly and severely than that which was not moistened. The conclusion is drawn that ultra-violet in the radiation from the quartz mercury burner and from the sun produced these injuries by modifying

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

the protein of the cells of the crystalline lens and of the skin in such a manner that the salts present can combine with it to form a coagulum.

Cataract is prevalent among people living in India and among glass blowers. Analyses of human cataractous lenses from the United States show a great increase in the salts of calcium and magnesium and those from India in addition an appreciable amount of sodium silicate. Tropical light is comparatively rich in ultra-violet radiation. Silicious earths form part of the diet of certain classes in India. To explain the prevalence of cataract among people living in the tropics and among glass blowers the assumption is made that ultra-violet radiation modifies the protein of the lens so that the salts of calcium and of magnesium and sodium silicate when present in abnormal amounts can combine with the modified protein of the lens to form a coagulum and hence an opacity or cataract.

The wave-lengths in the ultra-violet region of the spectrum effective in changing the protein so that certain salts can combine with it to form a coagulum lie between $254\mu\mu$ and $302\mu\mu$ inclusive.

It has been recognized for some time that, unless protected by a glass globe, the radiation from a quartz mercury arc or from an iron arc or from any light source emitting large quantities of ultra-violet rays is harmful to the eye. In a general way it has been assumed that all radiation of shorter wave-lengths than $350\mu\mu$ is injurious to living tissues. So far as I know little or no attention has been paid to the mode of action of this radiation in producing the injury. The object of this investigation, among other things, was to determine which wave-lengths in the ultra-violet region of the spectrum are injurious to living tissues and the mode of action of these wave-lengths in producing the injury.

An organ, *e.g.*, the eye, is composed of tissues, connective tissue, nervous tissue, etc. The tissues are composed of cells. The most important constituent of the cell is the protein. Protein is a nitrogenous, semi-fluid organic compound, colloidal in nature. Egg white is a good example of a protein. This, however, consists of several proteins. Dreyer and Hanssen[1] showed that egg white is converted into an opaque coagulum by exposure to ultra-violet radiation just as it is when it is heated to 100° C.

I exposed free-swimming organisms, paramecia, to the radia-

[1] Dreyer and Hanssen; *Comptes Rendus*, 1907, vol. CXLV, p. 234.

tion from a quartz mercury burner and observed them under the microscope during the exposure. These organisms are fairly transparent and are just visible to the unaided eye. During the exposure they moved more and more slowly and gradually became more granular and opaque. After twenty or thirty minutes the organisms were dead. Fig. 1 (1) represents the normal transparent animal, (2) represents an organism that was killed by ultra-violet radiation and (3) one killed by heating to 45° C. It may be seen that whereas the normal animal (1) is transparent, (2) and (3) are both granular and opaque. As exposure of egg white to ultra-violet radiation caused it to lose its transparency and to become an opaque mass, so the exposure caused the living material or protoplasm of these organisms to coagulate and to become an opaque mass. The conclusion may be drawn that ultra-violet radiation injures or kills living cells by coagulating or rendering insoluble the protoplasm or living material of the cells.

Experiments were carried out in an attempt to determine the mode of action of ultra-violet radiation in coagulating or rendering insoluble the protein of cells and to determine the specific wave-lengths in the quartz mercury arc active in this respect. A normal excised crystalline lens was placed between two quartz plates and pressed into a thin layer by squeezing the plates together. By means of a quartz spectrograph the spectrum from a quartz mercury burner operating at 70 volts and 800 candle-power was focused on the layer of lens material. This layer of material was almost perfectly transparent. The exposure was made for one hundred hours. At the end of this time there was no visible change in the material. It was as transparent as at the beginning of the experiment. However, when the preparation was immersed in a 0.1 per cent. calcium chloride solution four bands of coagulated lens protein appeared where the bands of the spectrum had been focused. Fig. 2 (3) is a photograph of the preparation after it had been immersed in the calcium chloride solution; (1) is a photograph of the spectrum that was focused on the material. It may be noticed that the lens material (3) was precipitated in the extreme ultra-violet region of the spectrum where the photographic plate (1) was not affected.

A similar preparation was made except that the lens was soaked in a 0.1 per cent. solution of calcium chloride for several hours previous to being pressed between the quartz plates. The spectrum was focused on this layer of lens material just as it had been focused on the layer of normal lens material. After fifteen hours of exposure nine bands of coagulated lens material could be seen where the corresponding bands of the spectrum had been focused. Fig. 2 (2) is a photograph of the lens material on which the spectrum had been focused for fifteen hours. The line of coagulated lens protein in (2) where the spectral line of wave-length $254\mu\mu$ was focused appeared after sixty minutes exposure; that where the spectral line of wave-length $265\mu\mu$ was focused after seventy-five minutes of exposure. The other lines of coagulated lens protein where the lines of the spectrum was focused appeared after two hundred minutes of exposure.

Egg white was introduced into a quartz cell. The spectrum from the quartz mercury burner was focused on this material for fifteen hours. At the end of this time nine bands of coagulated egg white could be seen where the bands of the spectrum had been focused. These bands of coagulated egg white occurred where the bands of coagulated lens protein had occurred and the time of appearance of the different bands was about the same as those of the lens protein, (2) Fig. 2.

Egg white was poured on a glass plate and spread out in a thin layer. After the egg white was dry the spectrum from the quartz mercury burner was focused on it for fifteen hours. At the end of this time no visible change had been produced on the egg white by the spectrum. The glass plate with the layer of egg white on it was immersed in a 0.1 per cent. calcium chloride solution. In a few minutes nine lines of coagulated egg white appeared in the region of the spectrum where the lines of coagulated lens protein had appeared.

From these experiments it would seem that calcium salts in some way make it possible for ultra-violet radiation to precipitate protein. It would seem that ultra-violet radiation acts on the protein in such a way that calcium salt can combine with it and form a precipitate or coagulum. Magnesium salts and silicates have the same effect as the calcium salts.

Cataract is an opacity of the crystalline lens. Analyses of human cataractous lenses from America show a great increase in the salts of calcium and magnesium and those from India show in addition to these salts silicates. I am told that silicious earth forms a part of the diet of certain classes in India. This may account for the silicates in the cataractous lenses from there. Cataract is of very common occurrence in India. Tropical light is comparatively rich in ultra-violet radiation. To explain the prevalence of cataract in India, the assumption is made that the relatively great amount of ultra-violet radiation in tropical daylight acts on the lens protein in such a way that the silicates in the eye media can precipitate it and produce an opacity. To explain the prevalence of cataract among glass blowers, the assumption is made that the eyes of glass blowers are subjected to more of the short wave-lengths than the eyes of people generally and for this reason the protein of the lens is modified and if such substances as salts of calcium, magnesium or silicates are present in sufficient concentration the protein will be precipitated and the lens rendered opaque or cataractous. The glass blowers who develop cataract form a relatively small percentage of those engaged in that occupation. Since the eyes of those who do and those who do not develop cataract are exposed to the same quality and quantity of radiation from the furnaces, it is assumed that those who do develop it have a disturbed condition of nutrition expressing itself in an increase of those substances which can precipitate the protein of the lens acted on by ultra-violet radiation.

PRODUCTION OF AN OPACITY IN THE LENS OR CATARACT IN LIVING ANIMALS.

Experiments were carried out in an attempt to increase in the fluids of the body of living animals and hence in the eye media, those substances found to be greatly increased in cataractous lenses with the hope that on exposure of the eyes of the animals to ultra-violet radiation cataract would develop. Many observers have demonstrated that it is impossible to produce an opacity of the lens or cataract in a normal living animal by exposure of its eye to ultra-violet radiation. Burge[2] showed that it was im-

[2] Burge; *Amer. Jour. of Phys.*, vol. XXXVI, 1914.

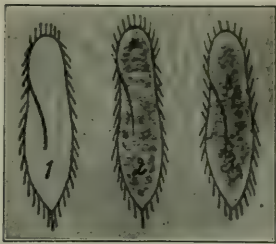


Fig. 1.—Paramecia. (1) the normal transparent animal. (2) Paramecium killed by ultra violet radiation. (3) Paramecium killed by heating to 45° C.

Fig. 2.—Photograph of spectrum of quartz mercury arc. (1) Made on a photographic plate. (2) Made on lens protein extracted by 0.1 per cent. calcium chloride. (3) Made on a thin layer of lens, immersed in 0.1 per cent. calcium chloride after the exposure.

Fig. 3.—Fish (1) living in tap water and exposed to ultra-violet radiation for 12 hours. Fish (2) living in 0.1 per cent. sodium silicate and exposed to ultra-violet radiation for 12 hours. Fish (3) living in 0.1 sodium silicate and exposed to ultra-violet radiation for 24 hours.

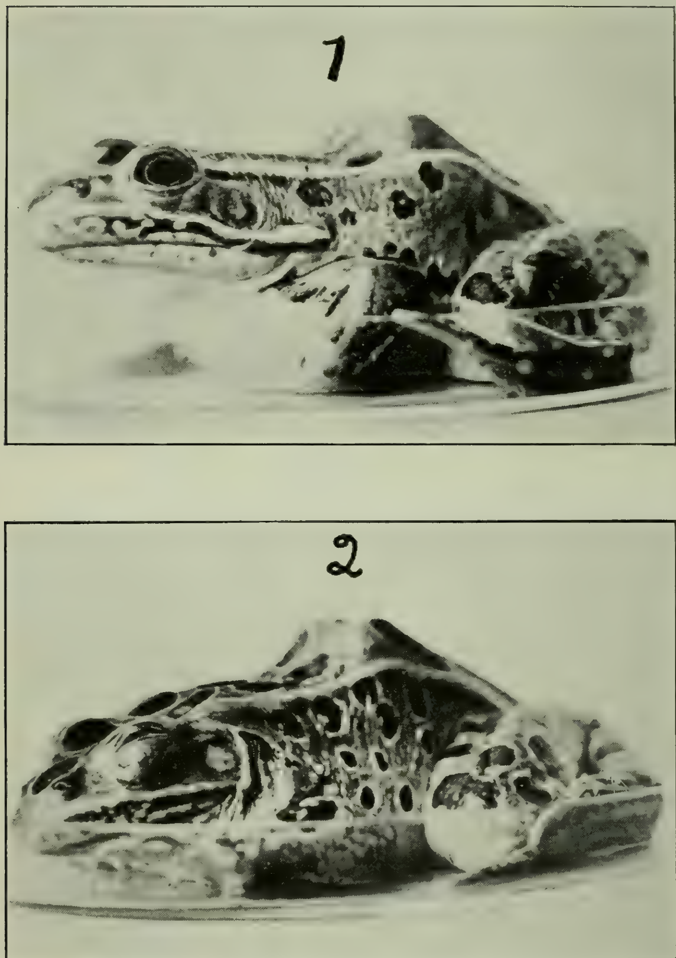


Fig. 4.—Frog (1) living in tap water and exposed to ultra-violet radiation for 5 hours. Frog (2) living in 0.2 per cent. sodium silicate and exposed to ultra-violet radiation for 5 hours.

possible to produce an opacity of the excised lens exposed directly to ultra-violet radiation for very long periods. Fish were chosen for the experiments because they could be kept alive in the solutions of the salts desired. One batch of gold fish was kept in 0.8 per cent. calcium chloride, another in 0.8 per cent. calcium lactate, another in 1.0 per cent. dextrose, another in 0.1 per cent. sodium silicate for ten days. At the end of this time each fish in its turn was introduced into a small box with a quartz window in one side. In practise four of these boxes were used so that four fish were exposed at one time. Clear tap water was kept flowing through these boxes during the exposure. The boxes containing the fish were adjusted so that the quartz windows were 15 cm. from a quartz mercury-vapor burner operating at 140 volts, 3.3 amperes and 2,400 cp. In this manner one eye of each fish was exposed to the radiation. Each exposure was of six hours' duration. After the exposures the batches of fish were replaced in the solutions from which they were taken. For comparison the eyes of fish living in tap water were exposed in the same manner and for a similar length of time as those living in the salt solutions. As a rule a slight opacity in the cornea of the eye exposed appeared about fifteen hours after the first exposure.

Ten days after the first exposure the eyes of the fish that had been exposed were exposed again for another six-hour period. At the time of this second exposure as a rule an opacity of the cornea and lens of the fish living in the salt solutions had increased while the opacity of the cornea of the fish living in tap water had cleared up. Several hours after the second exposure as a rule the opacity of the lens and cornea of the fish living in the salt solutions became more marked. An opacity of the cornea of the fish living in tap water also developed, but it was slight and cleared up in a few days, while that of the fish living in the salt solutions increased.

After the second exposure no prescribed rule as to time for the third exposure can be laid down. In order to clear up the opacity of the cornea of the fish in the different salt solutions, it is necessary to transfer them to tap water. As a rule the opacity of the cornea will clear up in a few days, while the lens

remains opaque. By nursing, by exposing to ultra-violet radiation, by transferring back and forth from salt solutions to tap water, I have been able to obtain fish in the condition indicated in Fig. 3. Fish 1 had been living in tap water in the laboratory for thirty days and had been exposed to ultra-violet radiation for two six-hour periods or twelve hours. Fish 2 had been living in 0.1 per cent. sodium silicate for twenty-eight days and had been exposed to ultra-violet radiation for two six-hour periods or twelve hours. Fish 3 had been living in 0.1 per cent. sodium silicate for forty-two days and had been exposed to ultra-violet radiation for four six-hour periods or twenty-four hours.

It may be seen that the lens of fish 3 living in the silicate solution and exposed to ultra-violet radiation for twenty-four hours had become perfectly opaque, that of fish 2 living in the same solution but exposed to ultra-violet radiation for twelve hours had become partially opaque, while the lens of fish 1 living in tap water and exposed to ultra-violet radiation for twelve hours was practically clear. The results of these experiments would seem to support the assumptions made in explaining the prevalence of cataract among people living in the tropics and among glass blowers.

THE PRODUCTION OF ANTERIOR EYE TROUBLE BY MEANS OF ULTRA-VIOLET RADIATION.

One batch of frogs was kept partially immersed in 0.2 per cent. sodium silicate, another in 0.8 per cent. calcium chloride, another in 1 per cent. dextrose for fifteen days. The eyes of these frogs were exposed to the radiation from a quartz mercury burner at a distance of 20 cm. one hour each day for five successive days. Photographs of the frogs were made fifteen days after the exposures. Fig. 4, frog 2 had been living partially immersed in 0.2 per cent. solution of sodium silicate previous to the exposure. Frog 1 had been living partially immersed in tap water for the same length of time. It may be seen that the skin covering the anterior part of the eye of the frog living in the salt solution had been coagulated and converted into an opaque mass, while that of the frog living in tap water was very little injured. The solution of calcium chloride and of dextrose had the same effect as the solution of silicate. The conclusion may

be drawn that salts such as are found to be greatly increased in human cataractous lenses not only increase the effectiveness of ultra-violet radiation in producing an opacity of the lens or cataract, but they also increase the effectiveness of ultra-violet radiation in producing anterior eye trouble.

The skin is more easily sunburned when it is wet than when it is dry. Sunburn is a precipitation of the protein of the cells of the skin by the ultra-violet radiation in sunlight. Ultra-violet radiation acts on the protein of the cells of the skin in such a way that certain salts in the lymph bathing the cells can combine with it and precipitate it. If the skin is wet, the salts in the water facilitate this process.

CONCLUSIONS.

1. Ultra-violet radiation kills living cells and tissues by changing the protoplasm of the cells in such a way that certain salts can combine with the protoplasm to form an insoluble compound or coagulum. The effective region of the spectrum in coagulating the living material of the cell or protoplasm is between $249\mu\mu$ and $302\mu\mu$. The most effective region is around $254\mu\mu$ in case of the mercury arc used.

2. An opacity of the lens or cataract can be produced in fish living in solutions of those salts found to be greatly increased in human cataractous lenses by exposing the eye of the fish to ultra-violet radiation. This cannot be done with fish living in tap water.

NELA RESEARCH LABORATORY,
NATIONAL LAMP WORKS OF GENERAL ELECTRIC CO.,
Nela Park, Cleveland, Ohio.
August 25, 1915.

DISCUSSION.

MR. W. R. MOTT: Referring to glass 1 millimeter thick not absorbing ultra-violet light at $300\mu\mu$, I think it makes an enormous difference what kind of glass is used. The ordinary window glass really cuts off ultra-violet quite well; therefore a statement of the kind of glass[1] referred to might be of advantage. I

[1] Note on Non-transmission of ultra-violet ($300\mu\mu$) through glass; p. 94, E. C. C. Baly's book on Spectroscopy; p. 3, Plotnikow, Photochemische Versuchs-technik Lepzig, 1912, Akademische Verslagsgesellschaft; pp. 301 and 335, Eder's Handbuch ber Photographié, 1912; p. 608, Light Energy by Dr. M. Cleaves.

have made a few little experiments on the coagulation of albumen with different kinds of flame arcs. With the white flame arc there is very little coagulation if cooled by air or water when very near the arc. With an iron arc there is very marked coagulation.

Relative to the point that some people who are afflicted with cataract have diabetes, I call attention to the fact that uranium has been used as a homeopathic remedy for diabetes, and in large doses, undoubtedly produces conditions of chronic nephrities. Uranium has another interesting characteristic: it responds to the action of light in the presence of organic material, causing very severe decomposition of almost any organic acid. The combined action of the chemical and of light produces entirely different results from the action of either alone. The same is true to a limited extent of iron, and this again raises the question: What is the chemical reaction in some of these cases? In that connection, I have been doing some experiments on dye fading,[2] and in looking up the literature, I find that dyes ordinarily are not faded if they are placed in a vacuum where the oxygen cannot get at them; and I saw a reference to the statement that bacteria are not killed by ultra-violet light in a vacuum.[3] I don't know how true it is, but it is an interesting statement.

Another valuable article is that by N. P. Peckoff on "Quantitative Light Filters for the Ultra-Violet Part of the Spectrum," which has appeared in the *Journal of the Russian Society of Physical Chemistry,* vol. 47, pp. 918-942, 1915.

A simple and easy test for determining the presence of the ultra-violet light is much desired. I have worked on about nine different tests. A well known test is to use paraphenylendiamine, which is white, on weighted blotting paper with nitric acid and quickly dry. This turns blue or green blue in the presence of ultra-violet light (radiations beyond about 380$\mu\mu$), and is a very satisfactory test because it is unaffected by ordinary light. The amount of ultra-violet light in sunlight, by the way, with that test is a little greater than it is with the white flame arc. As an-

[2] Mott W. R., A paper read at the Sept. 1915, meeting of the American Electrochemical Society. Use of the Flame Arc in Paint and Dye Testing.

[3] Hirshberg L. K., Scientific American, vol. 112, p. 313, April 3, 1915. Review of French work of Prof. Roux.

other test, lithopone, under the action of ultra-violet light, darkens very readily and is a very good test though somewhat slow.

DR. J. W. SCHERESCHEWSKY: I think that Prof. Burge's statements are extremely interesting and offer some very valuable suggestions for further investigation in this interesting field. I should like to ask Prof. Burge a few questions in regard to his work. While it is quite possible that the ultra-violet content of light, in the light of Prof. Burge's experiments and of the speculations of other people, might have something to do with the production of cataract, it is rather hard to see how glass blower's cataract can be produced by the ultra-violet component of light. According to Prof. Burge's researches, it is evident that the active region, so far as ultra-violet light is concerned, is rather closely restricted to wave-lengths which are shorter than 302 millimicrons. It is hard to see how the light from molten glass, at the temperature at which the furnaces are held, can produce such ultra-violet light. At this temperature it seems to me extremely unlikely that there would be any ultra-violet radiation from glass furnaces of a wave-length shorter than 360 millimicrons. I should like to ask Prof. Burge what, if any, effect was observed in the eyes of fish placed in the solution of mineral salts while they were becoming adapted to the solution? Of course, if one goes into an aquarium there will be seen a number of fishes which though apparently exposed only to the water, tap water or artificial sea water as the case may be, which suffer from corneal opacities of various kinds and often from cataracts. Now, of course, we ought to presume, from Prof. Burge's paper, that fish living in these mineral solutions were unaffected by those solutions until they were exposed to the ultra-violet light; but I should like a definite statement in regard to any effects which might have been observed in the eye apparatus of fish due to the solutions alone. I suppose, too, that the boxes in which the fish were placed were so narrow that it was impossible for more than one eye of the fish to be exposed to the light. I notice that while the photograph on the fifth page shows the spectral regions which are most effective in producing coagulation and that undoubtedly certain portions of the spectrum which are apparently effective in producing coagulation of protein material, may penetrate the

cornea, we have to remember that the cornea may be somewhat variable in its transmission. Most figures for the transmission of the cornea show that absorption is complete of wave-lengths shorter than 300, but there seems to be room for considerable individual variation in this respect, in that the tissues of young animals are more permeable to ultra-violet rays than those of older animals. Inasmuch as cataract is usually a development in the aged, I do not know that we can always infer that the absorption of the cornea is within the limits of 300 in such cases. I mean that in older persons it is quite conceivable that the cornea may have become more opaque, so that the absorption, instead of stopping at 300, may possibly extend to 305. In this way the spectral regions shown by Mr. Burge to be especially active would be prevented by corneal absorption from acting on the lens.

Mr. I. G. Priest: It is stated commonly that the tanning of the human skin is due to ultra-violet light. I should like to know whether there is a definite source for that statement and also, is there any work which shows the cause of the difference in the action of the light upon different individual skins? It is well known to people who are out in the summer time that some people tan and get a nice, leathery tan, while others repeatedly burn and never get a tan. Has any scientific work been done on that subject?

I am interested in the question Mr. Mott raised as to whether it is true that bacteria are not killed by ultra-violet light in the absence of oxygen? I can answer Mr. Mott's question by experiments I have recently made myself on cotton seed oil. The color is very permanent when exposed to direct sunlight, that is, sunlight that comes through a thin layer of glass, *if sealed in a vacuum,* while a sample of the same oil exposed to the same sunlight, with a thicker layer of glass but in contact with the atmosphere, will fade in a very few hours from amber to nearly water white. The same sample, exposed in a vacuum, in three weeks' exposure to all the sun that would shine, showed no change in color as followed colorimetrically on the Arons chromoscope.

On the seventh page very specific data are given in regard to dimensions distances of lamps, etc,. but not as to the dimensions of the box in which the fish was contained, nor as to the thickness

of water between the quartz window and the eye of the fish. I should think it would be well, in revising the paper for the TRANSACTIONS, to add these data. And it seems to me rather vague to specify water, where one is interested in the mineral content of the water, merely as "tap water." I presume that it was Cleveland tap water, which would be different from Washington tap water, St. Louis tap water or other tap waters. Wouldn't it be well to supplement the statement with an analysis of the tap water, or perhaps better to have made the experiments in distilled water?

DR. E. P. HYDE: It has been my privilege and pleasure to follow the experiments of Dr. Burge throughout most of their course. There is one point he did not mention, and I presume that he did not, consistent with the idea which he presented that he does not care to insist upon the explanation of various phenomena which one encounters, on the basis of these experiments, but prefers rather to let the experiments stand for themselves. There is one point, however, which I think of interest, and inasmuch as it has been raised by one of the other speakers before myself, I should like to refer to it, namely, the production cataract in the eyes of glass workers. I had the pleasure, some years ago, of talking with Dr. Parsons, at the time when the Governmental Commission was being formed in England, to consider this question. The results of the investigation in England, as published by Professor Crooks, indicated—if I may use the word indicated, because I scarcely think that the data which were presented by Crooks would justify such a conclusion—indicated to him at least, or suggested to him, the significance of infra-red rather than ultra-violet radiation as the cause of the malady. One of the first experiments Dr. Burge performed was to expose the excised eyes of pigs and cattle to radiation of different wave-lengths. He exposed the eyes to ultra-violet radiation, and under conditions of modified nutrition, obtained cataractous lenses. He exposed the eyes to intense radiation in the visible region and secured no evidence of cataract. He placed the opening of an electric furnace at about 1,000° or 1,200°, very, very rich in infra-red radiation, as close to an eye as he could without actually burning

the eye by the heat, and in all cases in which he was able to keep the lens at a reasonable temperature, he obtained no indication whatever of any modification which, in the presence of the saline solutions, would produce cataract. That may be taken for what it is worth. I do not say that this proves that infra-red radiation may not play a part. I do not think it proves that ultra-violet radiation is the actual cause of cataract in the eyes of glass workers, but the fact itself is significant and anyone may draw whatever conclusion he wants to draw from it. From what I have heard from Dr Burge, he is not willing to draw positive conclusions, but I think it is significant that infra-red radiation in such quantity and intensity as he has obtained did not produce cataract or modify the lens in any such way that cataract was ultimately produced with the saline solutions, and that ultra-violet radiation did modify the lens in such a way that cataract was formed. The paper, as a whole, marks a distinct advance in our knowledge of the effect of radiation.

Dr. H. P. Gage: Since the investigation of Crooks, everybody interested in the manufacture of spectacles has taken a sudden and deep interest in getting a glass which, in a thin layer of one or two millimeters, would cut out ultra-violet rays, and we are certainly very glad to know what radiations are of the greatest danger; one might say fatal radiations. The question whether radiations nearer the visible are harmful could only be determined by very long experiment. We are also glad to learn something of the effect of the infra-red. Apparently the eye needs no protection from the infra-red when working with any source except where the intensity of the light or the infra-red is so great that there is danger of actually cooking the tissues of the eye by the thermal effect of the infra-red, and then it simply becomes a question of getting a glass which will cut down the infra-red enough for comfort when working.

Mr. I. G. Priest: In regard to the suggestion just made by Mr. Gage, I know the opinion seems to be current that there is a cooking of the tissues. Now I do not pretend to know anything about biology, but Dr. Schereschewsky is here and can perhaps answer. Isn't that idea absurd upon the face of it? Any amount of energy that could go into the eye could not possibly

raise the temperature of the lens, (as long as the subject is living), enough to cook it. That is, would it ever get above a fever temperature?

DR. SCHERESCHEWSKY: No, I hardly think that is possible at all. Any injurious temperature like that would certainly burn the skin long before it could possibly affect the tissues of the eye itself. As a matter of fact, the conjunctiva, which is very effective in absorbing infra-red radiation, will probably not transmit more than 10 per cent. of all the infra-red radiation falling on the eye.

There was one other question Mr. Priest brought up which I would like to mention in regard to tanning and sunburn. I notice that Dr. Burge, in his paper, states sunburn is a form of coagulation. I do not know whether that is so or not; but it has been noticed, especially in the last few years, when exposure to the sun has become a rather favorite method for improving the condition of persons suffering from tuberculosis, that if, in the process of acquiring a good tan, excessive sunburn is permitted, this retards very much the development of pigment in the skin which is the result of tanning. The object of this treatment by tanning is to improve the metabolism; that is all it does. The aim is to cover the entire body with as deep a coat of tan as can be secured. Certain precautions are adopted, the exposure must be very gradual and must be only a few minutes to start with. The entire body cannot be exposed, but only certain portions, first the extremities and then the thorax. If the exposure goes as far as severe sunburn, the deposition of pigment is interfered with. Dark persons tan deeply; very blonde persons are almost incapable of tanning under usual circumstances, but by careful exposure one finds that even very blonde persons, with a correspondingly small amount of pigment in the skin, are capable of taking a fair amount of tan. If severe sunburn is allowed, it so alters the protective functions of the skin that tanning does not develop so well as when sunburn is avoided. The protection afforded by a good coat of tan is very marked. There are marked individual differences; some persons have such good pigment production that they can stand any amount of sunshine and it will merely intensify the deposit of

pigment in the skin. On the other hand sunshine, in others, produces an amount of reaction which prevents good pigmentation.

MR. I. G. PRIEST: Chemically, what is the difference between sunburn and tan?

DR. SCHERESCHEWSKY: Sunburn is a reaction of the skin to ultra-violet rays and is quite comparable to a slight burn, whereas tanning is a protective which consists in the deposition in the skin of absorbing pigment.

DR. W. R. BURGE (In reply): Only one eye was exposed and the other was not exposed. The unexposed eye was the control. So far as the objections to the carrying out of our experiments on living animals in tap water is concerned, and the suggestion that we should have used distilled water, it is known that living protoplasm is killed by distilled water. I think that Dreyer and Hansen exposed many substances to the radiation from a quartz mercury-vapor burner. In Parke-Davis' laboratory the work has taken up during the last year or two and many more additional substances have been exposed to the radiation from a quartz mercury burner. So far as glass blower's cataract is concerned, I do not wish to say anything about the application of this work or whether it may be applied or not. I think such discussion would be futile, and all that can be done is to take the experiments for what they are worth. If the experiments have any practical value it is to be hoped that such application may be made in due time. So far as the experiments on the tanning of the skin are concerned, these were incidental. Anyone can perform the experiment for himself, if, before going out to row, he wets one side and leaves the other dry. It will be found that the wet side always sunburns much more quickly than the dry side. The salt in solution on evaporation of the water on the skin, becomes more concentrated, and acts as the salt in these experiments. I don't know of any data on the subject.

MR. PRIEST: Was your experiment made with salt water or fresh water.

DR. BURGE: Fresh water from Lake Erie.

ARTIFICIAL ILLUMINANTS FOR USE IN PRACTICAL PHOTOGRAPHY.*

BY C. E. KENNETH MEES.

Synopsis: Artificial illuminants can be used in negative making for portraiture, cinematograph work and photo-engraving. For portraiture diffused sources are necessary, and either a large source must be used or the light must be reflected from a large area. In cinematograph work about a quarter kilowatt per square foot of stage is used, the usual arrangement including the use of mercury-vapor lamps overhead and at one side of the stage, and arcs in front. For photo-engraving an arc lamp is hung on each side of the copy board, most engravers using flame carbon arcs.

For printing papers the enclosed arc is used for silver papers while for platinum the mercury-vapor lamp is satisfactory. In printing fish glue on metal it is important that a small source of light should be used in order to get sharp definition of the dots, and the printing should be as far away as possible. The photographic efficiency of artificial illuminants depends upon their quality and upon their visual efficiency, but must be considered from the point of view of the materials used, which materials are of three chief kinds: (1) panchromatic materials sensitive to the whole spectrum and used with filters to give a rendering similar to that seen by the eye, or for color photography; (2) ordinary materials having their maximum sensitiveness in the blue violet; (3) materials sensitive only to the ultra-violet. For panchromatic materials the efficiency of the illuminant will depend almost entirely upon its visual efficiency, while for ordinary materials the chief point of importance is the efficiency in the blue violet, but since the latitude and freedom from halation increase with shorter wave-lengths it is better to use light sources having their maximum near $400\mu\mu$ rather than near $470\mu\mu$. It is pointed out that nearly all artificial illuminants have application in some branch of photography or other.

While in the early days of photography almost the only source of light was the sun, the application of artificial illuminants to the art is continually increasing. The illuminants which are available are of many kinds, and, indeed, include all the more powerful sources of light. The advantages of artificial illuminants which have caused their introduction are chiefly their constancy and their ready availability; the variation of the intensity of natural light makes the judging of the time for which the sensitive material is exposed a difficult task, so that the photog-

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

Communication No. 31 from the Research Laboratory of the Eastman Kodak Company.

rapher has to acquire considerable skill and experience in order to avoid obtaining results showing the effect of incorrect exposure, while with most artificial illuminants the matter of exposing can be reduced to a simple calculation of time, thus eliminating one chance of insuccess. The possibility of working at any time under evenly uniform conditions is certainly an advantage in such divisions of photography as photo-engraving, trade enlarging and, indeed, all commercial work; while it is a further advantage that the artificial sources of light are available whenever they are required and that the worker is not confined to a small portion of the day or to an intensity dependent on meteorological conditions.

One may summarize the purpose for which artificial illuminants are used and the properties required in the illuminant when it is applied to a particular purpose somewhat as follows:

Negative Making: *Portraiture.*—For portraiture a large diffused light source is a necessity in most work and only occasionally can a concentrated source be used. Consequently, either a very extended source such as that given by the mercury-vapor lamp must be employed, or else a completely diffusing system is arranged; thus, for an arc it is convenient to place the reflector behind the arc so that the light is directed away from the sitter on to a large secondary reflector, which may be a wall, though it is usually more convenient to have a movable arrangement. Whatever system is used for obtaining a large source of diffused light curtains and screens are necessary so that the operator can adjust the area and direction of the light at will. An arrangement which has given satisfaction consists of a battery of 12 or 16 nitrogen tungsten lamps placed in a frame behind a diffusing medium and covering an area of 30 or 40 sq. ft., the area to be utilized being modified by applying independent control to the separate lamps.

Cinematograph Work.—In moving picture studios a considerable amount of light is necessary owing to the speed at which the pictures are taken, the exposure being only 1/40 of a second with an aperture of about F/8. The average stage, including an area of perhaps 240 sq. ft., requires about 60 kilowatts for illumination, and a typical arrangement of the lights will consist of 40 to 50 kilowatts expended in mercury-vapor lamps or quartz arcs arranged about 12 to 15 ft. above, as a roof to the stage and down

one side to a distance of about 3 ft. from the floor, and about 12 kilowatts used in some form of arc, conveniently a flame arc, about 10 ft. in front of the stage and the same distance from the floor; such an arrangement is typical of many of the stages used by the large producers of moving pictures in this country and the importance of artificial illumination in this work can be realized when it is understood that many producers will have six such stages working at a time.

Photo-Engraving. In photo-engraving the copy-board is generally lighted by an arc lamp hung on each side. In the earlier days these were usually open arcs and later, especially in Europe, the enclosed long flame carbon arc came into use, and is still very convenient for work with wet collodion, but it is unsuitable for color work owing to the deficiency of red and especially of green light. In this country many photo-engravers use open arcs with white flame carbons, which appear to be quite satisfactory. The quartz lamp would be suitable for black and white work if it came up to efficiency in less time, but a great lag in reaching efficiency is against it. Neither the quartz lamp nor the mercury-vapor lamp seems to be as efficient as the flame or enclosed arcs; for color work the nitrogen tungsten lamp might perhaps be applied to advantage.

For color photography, such for example as color portraiture, the most important thing about a lighting system is the constancy of the quality of the light; but high intensity is required and the conditions as to size of source already explained under portraiture fully apply: we have adopted the battery of nitrogen tungsten lamps already spoken of as being very suitable for color portraiture.

In ordinary photographic printing the Aristotype and solio papers which used to be very popular are often printed by means of a large enclosed arc instead of daylight, and this seems to be very suitable for the printing of such silver papers. For platinum printing, however, it is advisable to use a source of light which is not so hot, as the heat is very liable to give mealy prints. One large company do their trade printing by means of mercury-vapor lamps which are held constant by a resistance and ammeter, the current being watched and the printing being done entirely by time.

Bromide and chloride papers are, of course, printed by artificial light exclusively, the usual printing cabinet containing tungsten lamps, though for quick trade work an arc lamp or mercury-vapor lamp is frequently used, thus enabling very short exposures to be given.

For enlarging it has been customary to use an open arc, but if a condenser is used, it would seem to be better to employ a condensed filament tungsten lamp because of its great constancy, the changes in the intensity of an arc making accurate exposure difficult unless the arc is one which permits of very good regulation. Much enlarging in trade houses is done without a condenser, the negative being lighted by a diffusing screen behind which the source is placed, such a suitable diffusing screen being a sheet of opal glass. For such work suitable illuminants are the enclosed flame or open white flame arcs, but if mercury-vapor lamps are used, a powerful diffuser is not needed, a sheet of ground glass being sufficient if the tubes of the lamp are arranged so that there are a number parallel to each other a short distance apart.

For the printing of fish glue or a similar resist on metal in photo-engraving it is important to have a small source of light in order to get sharp dots, as otherwise a very high pressure is required to ensure sufficiently good contact; and it is, indeed, almost impossible to print dry plates made on ordinary sheet glass by means of large sources of light. The arc must necessarily be powerful, but the flame should be as small as possible and the distance as great as can be used in order to prevent the exposure being too long. It would appear that for metal printing there is an opening for the development of some form of lamp in which approximately parallel light of high intensity is obtained.

For some photographic purposes constancy and lack of flicker are essential, average constancy being important in almost all photographic operations. Flickering is a less serious disadvantage in many operations than lack of average constancy, but where the exposure is short, as in developing out printing, enlarging or photo-engraving, flickering of the light source is very much to be deprecated, and this is a great disadvantage of enclosed and open arcs. The table on the fifth page summarizes the advantages and disadvantages of various illuminants for different classes of work,

Illuminant	Open arc	Enclosed arc	Flame arc	Mercury vapor	Quartz arc	Nitrogen tungsten	Blue glass tungsten nitrogen
Cine work	Fair	Fair	Good	Good	Good	Poor	Fair
Portraiture	Fair	Good	Very good	Very good	Not suitable	Fair	Good
Color portraiture	—	—	Very good	—	—	Very good	—
Color engraving	Fair	Poor	Very good	—	—	Good	—
Photo engraving (black and white)	—	Good	Good	—	Fair	Very poor	Poor
P. O. P. printing	Fair	Very good	Good	Good	Good	—	—
Platinum printing	Poor	Poor	Fair	Very good	Fair	—	—
Carbon printing	Fair	Good	Very good	Poor	Poor	—	—
Fish glue printing (photo-engraving)	—	Good	Good	—	—	—	—
Enlarging	Fair	Good	Good	Good	Good	Good	—

the efficiency, which is considered in the next section, being also taken into account.

In addition to the suitability of a light source as to size, constancy, intensity, etc., the efficiency and quality of the light must be considered. The visual efficiency and the quality taken together will represent the photographic efficiency, since this can be calculated if one knows the spectral energy curve, which is the quality, and the height of one portion of it which is given by the visual efficiency. This relation between the visual and photographic efficiency for a number of light sources and for three different classes of photographic materials has been dealt with by Messrs. Jones, Hodgson and Huse in their paper* presented to this meeting.

When we consider the quality and efficiency of an artificial illuminant for use in photography we are confronted with a problem of rather different type from that with which we meet when the illuminant is for visual use. The color sensitiveness of the human eye in different individuals is so nearly alike that we need consider only the visibility curve of the average human eye, which can be determined with sufficient accuracy by taking the mean of the curves obtained by a number of observers, afterwards rejecting any results where the sensibility is not approximately the same as that of the average as being abnormal or pathological cases which can be ignored in the general choice of an illuminant; but there is no such average sensitiveness in photographic materials. In dealing with the choice of an illuminant for photographic purposes we must consider the use to which it is to be put and the materials which are likely to be exposed by means of it.

There are three main groups of photographic materials as regards their spectral sensitiveness: (1) materials which have been sensitized by means of dyes to the longer wave lengths of the spectrum and which are intended for use with color filters either to obtain a rendering approximating to that perceived by the human eye or for use in color photography where exposures are made for two or more defined areas of the spectrum. These materials are usually known as "panchromatic." Panchromatic plates are sensitive to the whole visible spectrum, their sensitive-

* Published in this number of the TRANSACTIONS.

ness between $\lambda 500\mu\mu$ and $\lambda 600\mu\mu$ being about one eighth, and between $\lambda 600\mu$ and $\lambda 800\mu$ about one-tenth of their total sensitiveness to daylight. (2) Positive or negative materials sensitive only to the blue violet and ultra-violet regions of the spectrum, and with their maximum sensibility in the blue-violet region, these including all ordinary plates or films used for landscape or portraiture, dry plates used in photo-engraving, and all the printing materials which are developed, such as bromide or gas light papers. These materials have a sensitiveness extending from the ultra-violet to about $\lambda 500\mu\mu$, the sensitiveness diminishing rapidly with longer wave length after about $\lambda 460\mu\mu$. (3) Materials which are sensitive almost exclusively to the ultra-violet, such as printing out papers or the wet collodion plates used in photo-engraving.

These classes of materials do not coincide with those discussed by Messrs. Jones, Hodgson and Huse; their "ordinary" materials are my second class materials sensitive only to the blue and ultra-violet regions, and their panchromatic or orthochromatic materials are considered, as they explain, as being used without filters and therefore do not coincide with my first class, where the materials are considered as being used only with filters, because in practise color sensitive materials are almost always used with filters which correct the light affecting the plate so that the plate sensibility and the spectral energy curve of the light and the filter together produce a rendering comparable with that observed by the eye by daylight. A light source is therefore more efficient with these materials if it enables us to make use of a weaker filter to attain the same result.

For panchromatic materials the efficiency of an illuminant depends chiefly on its visual efficiency, since it is used under such conditions that the light affecting the materials is nearly the same as that to which the eye is sensitive. Any ultra-violet light is of no use whatever, since it must be cut out by the filters, but inasmuch as the most color-sensitive materials which can be made are still deficient in their red sensitiveness compared with their sensitiveness to the green or blue, it is advisable that the maximum energy of the light source should be shifted towards the red end of the spectrum as compared with daylight; in fact, the high-

est efficiency will be realized with a quality of light where the energy maximum is about $\lambda 600\mu\mu$, and any source approximating this, provided its spectrum is continuous or nearly continuous, will be of suitable quality, the decision as to which illuminant is to be used resting chiefly on the question of its visual efficiency and its suitability in other respects, such as area and steadiness.

The "ordinary" materials, which comprise by far the greater quantity of all photographic materials used, require a source of light of which the maximum is in the blue violet and, indeed, the energy maximum of these materials is between $\lambda 380\mu\mu$ and $\lambda 460\mu\mu$, varying somewhat from one material to another but having $\lambda 440\mu\mu$ as a fair average for the maximum of the negative materials of this group. The photographic efficiency, therefore, of a light for use in ordinary negative making depends upon its intensity around $\lambda 440\mu\mu$.

Another question than efficiency, however, enters into the choice of a light for negative making; the latitude of the photographic emulsion varies very rapidly with its absorption, and the scale, gradation, and latitude of photographic materials depend upon the wave-length of the light to which they are exposed, since the absorption varies greatly with the wave-length, the scale being greater the shorter the wave-length. Other things being equal, a negative taken by light of $\lambda 480\mu\mu$ will have a shorter and steeper scale and less perfect gradation than if it were taken by light of $\lambda 400\mu\mu$.

Halation is caused by the penetration of light through the emulsion and its reflection from the back of the support, there being more halation the longer the mean wave-length of the illuminant employed, since the emulsion is more transparent the lower the frequency of the light. Where halation is a difficulty, therefore, as, for instance, in portraiture or cinematographic work, it is desirable to use an illuminant where the photographic effect is largely in the ultra-violet rather than one which depends upon the longer wave-length end of the blue violet for its effect.

It is an advantage, therefore, both for the attaining of the best gradation and for the reduction of halation to a minimum to use for these ordinary materials light of an average wave-length as near as possible to $\lambda 400\mu\mu$ rather than light having its maximum near $\lambda 470\mu\mu$.

Illuminant	Open arc	Enclosed arc	Flame arc	Mercury-vapor	Quartz arc	Nitrogen tungsten	Blue glass nitrogen tungsten
Visual efficiency	12	12	29	23	37	17	9
Quality	a. Good	Fair	Very good	Useless	Useless	Very good	Poor
	b. Fair	Very good	Good	Good	Good	Good	Good
	c. Poor	Very good	Good	Very good	Very good	Useless	Useless
Photographic efficiency	a. As visual efficiency throughout						
	b. 10	62	52	47	79	6	5½
	c. Fair	Very good	Good	Good	Very good	Useless	Useless
Constancy	Poor	Fair	Fair	Good	Good but slow in reaching constancy	Good	Good

(a) When used with panchromatic materials and filter to reduce the visual luminosity.
(b) For ordinary negative and positive materials.
(c) For ultra-violet sensitive materials.

The third class of materials, sensitive only to the ultra-violet, naturally require illuminants producing as much ultra-violet as possible, and the efficiency of the illuminant depends largely upon the intensity of the ultra-violet light which can get through glass, because it must be remembered that the ultra-violet light which cannot penetrate glass is of no use in photography, where the lenses or negative supports will cut out all rays below $\lambda 330\mu\mu$. It may be mentioned that carbon tissue, photogravure tissue, bichromated fish glue and, in fact, all the materials which depend on the sensitiveness of bichromate are more sensitive in the blue-violet than in the ultra-violet, the maximum sensitiveness of these materials being near $\lambda 460\mu\mu$.

The table on the ninth page summarizes the various qualities of the chief artificial illuminants. The figures for visual and photographic efficiency are from the paper by Messrs. Jones, Hodgson and Huse, 100 being taken as the efficiency of sunlight.

It will be seen that almost all sources of artificial illumination have application in some branch or other to photography. Each source has its own particular sphere of application, and no one source is suitable for all purposes. Claims are often made on behalf of one or other method of producing light as being the ideal source for all purposes, but such exaggerated claims only do harm to the cause which they are intended to advance, and it is better to recognize that photography is a wide field, having many sub-divisions, and that nearly all sources of light can be applied with special advantage in some one or other of those divisions.

DISCUSSION.

MR. M. LUCKIESH: My side of this subject involving the development of a photographic tungsten lamp and the general application of the tungsten lamp to photography was presented before this Society in January (TRANS. I. E. S., vol. X, No. 2, p. 149, 1915), and I believe Dr. Mees is in general agreement with the conclusions presented in that paper. It is very difficult and I believe inadvisable to attempt to draw sweeping conclusions in dealing with such a subject as photographic illuminants, and I am glad to hear Dr. Mees qualify some of his conclusions while presenting his paper.

With the recent increase in the efficiency of tungsten lamps, there appeared the first important opportunity for the tungsten lamp to enter the photographic field, therefore we made an extensive study of the subject in relation to the tungsten lamp. This brought us into the practical application of our developments and we have long ago realized that in portraiture (the chief field at which we aimed) the personal opinions of photographers differed so that no general decisions as Dr. Mees attempts to give in his tables are worth much. If the author of this paper represented the composite portrait photographer his conclusion would be of considerable interest but very likely such is not the case because opinions are so varied.

The tungsten lamp at present can not be introduced into all photographic fields. It is operating at present with considerable success in portraiture, color photography, printing, enlarging, copying, and to some extent in moving-picture production. The principal development has been in the blue-bulb photographic tungsten lamp which emits a light that approximately matches daylight in color and by absorbing some of the rays that do not affect ordinary plates a light of high actinic value per lumen is obtained. The actinic value per lumen is roughly the same as daylight with the result that short exposures without glare can be obtained in portraiture. The actinic value and color of the light approaching closely to that of daylight, makes it possible to use this illuminant in combination with daylight. This has been a desirable feature in many cases. The success of the unit has been demonstrated by thousands of practical installations and demonstrators of a large photographic supply house are completely equipped with them. Opinions of noted portrait photographers are much more valuable than such a summary as is given in this paper by one who in presenting the paper stated that he could not qualify as portrait photographer or as an expert in most of the fields considered. Such a unit as the photographic tungsten lamp has an additional feature of merit namely the ease of control by rheostats or reactances. As I have stated on several occasions the lamps operate satisfactorily at normal voltage but inasmuch as photographic conditions are so different from ordinary lighting conditions, it is justifiable to operate these lamps considerably above normal voltage thereby taking advantage of a

tremendous gain in actinic value. Dr. Mees' data and conclusions are no doubt based upon normal operating voltage. They would have been still more favorable to the tungsten lamp if based on a voltage above normal which is justifiable.

Dr. Mees stated that in the moving-picture studio the aperture at which pictures are taken is F8. Several producers have stated to me that F5.6 is the maximum aperture necessary for indoor work and that on many sets F4.5 is used indoors.

The clear tungsten lamp has been found successful in color photography but Dr. Mees fails to give the blue-bulb photographic tungsten lamp any mark in this column. Apparently he believes it has no continuous spectrum because any illuminant having a continuous spectrum is at least "very poor" for color photography. Color photography is at present a very crude process yielding far from perfect results. I have found that the blue-bulb lamp yields practically the same results as daylight even when the same filters are used. Of course it is wasteful to throw away light that is photographically active and we would not recommend the blue-bulb lamp for general adoption in color photography. However, these are studios in which some work is done along this line. If these studios are equipped with blue-bulb photographic lamps for portraiture I wish to assure the operators that they can use these lamps very successfully for color-photography. Quite the same argument holds for enlarging. Dr. Mees fails to give a mark to the blue-bulb photographic lamp in this column which is again misleading.

One great advantage of a portable unit such as the tungsten photographic lamp is that it can be placed in any position. This is a dominating feature in portraiture after actinic value has passed the test. Dr. Mees does not lay any stress upon this point, but an acquaintance with a few hundred studios equipped with such a unit would convince him that there are many features to be considered in making out tables such as he has attempted.

Inasmuch as I have gone into detail on this subject on several occasions, I will not discuss it further but will conclude by stating that Dr. Mees has presented a personal opinion in this paper which loses weight inasmuch as he stated in introducing his paper that he could not qualify as an expert in many of the fields

which he discussed. After all the conclusions of those who use illuminants daily in various photographic fields will determine the future of photographic illuminants.

Mr. W. R. Mott: Dr. Mees' paper represents a very broad subject and one that deals with an enormous variety of processes. I admire very much his sound and careful treatment of the whole subject and I agree with him in nearly all respects. While admitting the superior efficiency of the flame arc, he has suggested some of the objections to the flame arc, namely, that of fumes, odor and the question of its being a concentrated source of light. With regard to fumes and odor, these can be taken care of by placing a little ammonium carbonate in a cabinet with a diffusing screen. Such a cabinet was exhibited two years ago before two hundred photographers and no one complained in the least of odor, although it was running (nearly continuously) during the four days. The construction of such a cabinet may be described as about 5 feet across, 7 feet high and 3 feet deep. It is arranged with the curtain at a 45° inclination both vertically and on the side so that a perpendicular from the center of the curtain enters the field where maximum illumination is desired. Such a cabinet (with white flame arc) has been in satisfactory commercial operation in a portrait studio for over five years in Cleveland. Since then others have been using the flame arc on quite an extensive scale.

Since, other things being equal, the test comes on the question of efficiency, I wish to call attention to the fact that the flame arc is ahead of all the other sources of light for efficiency in the high amperage arcs. This is shown in the following tables.

	Line volts	Arc volts	Amperes	Mean candle-power	Spherical photo. power
White flame arc (open)	115	63	28.0	5,130	100
Nitrogen lamp, clear globe	117	117	6.7	866	4
Nitrogen lamp, blue globe	115	115	8.5	485	5

The gas-filled incandescent lamp with a blue bulb taking 8.5 amperes gave 485 mean spherical candlepower. The candlepower for the 28 ampere flame arc was 5130. (For equal line wattage the flame arc gave over three times the candlepower.) The candlepower efficiency is not only much in favor of the white flame arc, but also there is the quality of the light which is an almost

exact duplicate of sunlight plus blue sky. This means that the light is bluer than that of the lamp with a blue glass bulb (and because of the higher content of blue, violet and ultra-violet), and the light is photographically more efficient.

DR. MEES: What was the material?

MR. MOTT: Solio paper.

DR. MEES: That is the most disadvantageous paper one could select; it is only sensitive to ultra-violet light.

MR. MOTT: I tested it through glass and found that the ultra-violet light of the white flame arc was nearly the same in amount and quality as in sunlight plus blue sky.

A MEMBER: Might I add that these tests were made for wet plates.

MR. MOTT: In regard to other photo-chemical reactions, as in dye fading, I have found that the time required with a 750-watt clear glass gas-filled incandescent lamp was 17 to 100 times longer at equal distances than with the white flame arc at 28 amperes on 115 line voltage.

I write these figures here in the tabe for comparison. Then, in addition to these factors (candlepower, quality of light, and dye fading tests) we must remember that the flame arc is capable of enormous improvement, and I would say that it is possible with known processes, by combining them all together to increase the efficiency not 100 per cent. but 300 per cent. In further examination of these efficiencies, I might say that a test was made by Lux, in which he showed that a gas-filled tungsten lamp using 495 volts had an effect photographically of 8850; while that of a 220 volt enclosed arc lamp of 9.3 amperes had a value of 243,000. The quartz mercury arc had a rather considerable change in photographic value with change in current, and after a certain amperage decreased in photographic intensity.

A paper, "The Commercial Light Sources in Photography," by Dr. H. Lux, *Electrotechnische Zeitschrift*, pages 203, 204, April 29, 1915, and Sheppard's book on Photochemistry, page 102, give some interesting data on the photographic power of various light sources.

The enclosed arc lamp on 110 volts at 28 amperes is not as efficient for action on solio paper or *blue print paper* as the flame arc at the same amperage. My tests on blue printing and on solio papers show two and a half to three times greater speeds for like line power. (On 220 volts, two to four high amperage flame arcs are used in series.) The important consideration is that the white flame arc on 110 volts is much more efficient than the efficient enclosed arc of high amperage. (Many photographic operators use flame carbons even under semi-enclosed arc conditions.)

DR. C. E. K. MEES (In reply): I would like the opportunity of just replying to the criticism with regard to the lens aperture in the cinematograph studios. I am sorry Mr. Luckiesh was misled, and only wish you could see an aperture of 4.5 in the studios; I shouldn't have any trouble whatever with sensitive materials. There is not enough depth on the stage in the focal plane to use such an aperture as 4.5. You can use it when you are working with your actors sitting down at a table, but when they chase each other over the stage and fall down stairs, it doesn't work. With regard to windows in studios, and the suggestion that they be made smaller and put nearer—that is satisfactory where one sitter is to be photographed; but studios are usually designed to take groups of not less than six people; so I think you must be prepared to make, for good workers and large studios, quite considerable windows. The artist himself will cut that window down ruthlessly with blinds, but you cannot help that.

With regard to Mr. Mott's point—I only referred to the fumes and odor of the flame arc when used for color photography. When a single lamp is used, there is no difficulty, but in color work you have to use an enormous number of lamps and it is quite a difficult problem to handle the fumes from the flame arc. I would like to make a suggestion to Mr. Mott, and I know he will take it as being from a neutral. He has published these figures before, and they created on me a very unfavorable impression. If an illuminating engineer wants to give figures, I think he ought to give them in watts per spherical candle.

As to comparisons on solio paper, that would be satisfactory if

it were stated that it was for the purpose of wet plates but not for ordinary photographic work. It is most important, when you have a perfectly good case, as Mr. Mott has on photographic efficiency, that you should make the most of the other fellow's case.

RELATIVE PHOTOGRAPHIC AND VISUAL EFFICIENCIES OF ILLUMINANTS.*

BY L. A. JONES, M. B. HODGSON AND KENNETH HUSE.

CONTENTS.

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Communication No. 30 from the Reasearch Laboratory of the Eastman Kodak Co.

INTRODUCTION.

It is well known that, of two light sources which measured visually are of equal intensity, one may produce a much greater effect on a photographic plate than the other. This is due to the fact that the spectral sensibility curve of the photographic plate differs greatly in shape and position from that of the retina. The maximum of the visibility curve lies at $555\mu\mu$, while the maximum of the spectral sensibility curve of an ordinary plate lies in the blue-violet region at approximately $460\mu\mu$. Hence, if we have two sources of equal visual intensity, one being bluish and the other yellowish in color, the blue source will produce the greater effect on the photographic plate. For these reasons it is not possible by a measurement of visual efficiency to decide upon the effectiveness of a source for photographic work; that is to say, the photographic efficiency is not proportional to the visual efficiency.

A further complication arises from the fact that different types of photographic materials have very different spectral sensibilities, ordinary plates being sensitive only to blue, while orthochromatic plates are sensitive to blue and yellow-green, and panchromatic to blue, green and red. The problem presented, therefore, is the determination of the relation existing between the visual and photographic efficiencies of various illuminants when used in connection with photographic materials having certain typical spectral sensibilities. In this paper the work is confined to high speed materials used for negative making, no attempt being made to cover the entire field of photographic sensitive materials.

METHOD.

The method adopted for obtaining the desired ratios is essentially that used in the determination of plate speeds, and is briefly outlined in the following paragraphs.

If a strip of the plate to be tested be exposed in such a way that successive areas receive exposures increasing by consecutive powers of 2, it will be found upon development that a series of spots of increasing opacity are obtained. By measuring the density of each of these spots and plotting the value obtained against the logarithms of the exposures given, a curve is obtained which is known as the characteristic curve of the plate. Such a curve is shown in Fig. 1.

The term "density" as used in this work is defined as follows:

$$\text{Let} \quad T = \text{Transmission}$$

$$\text{Then } \frac{1}{T} = \text{Opacity, O}$$

$$\text{and } \log O = \text{Density, D.} \qquad D = -\log T.$$

It will be noted by reference to Fig. 1 that the portion of the characteristic curve between A and B is a straight line. This line extended cuts the log exposure axis at O, and the value of the exposure at the point O is termed the "inertia" of the plate. This "inertia" value is proportional to the insensitiveness of the plate, and the reciprocal of the inertia is proportional to the sensitiveness or speed of the plate. Speed numbers for a plate are obtained by multiplying the reciprocal of the inertia by some arbitrarily chosen constant. The inertia value obtained does not in general depend upon the time of development or upon the constitution, concentration, or temperature of the developer used. In Fig. 1, curve *a* was plotted from a strip developed three minutes, and curve *b* from one developed six minutes. It will be noted that the straight line portion of each curve cuts the log E axis at the same point, showing that the inertia value is independent of the time of development.

The value of the inertia, however, does depend upon the quality of the light to which the plate is exposed. Thus, if the plate is sensitive to blue light only, a lower inertia (higher speed number) will be obtained when a bluish light is used than when one of yellowish color is employed. Hence, for a standard source for

use in sensitometry it is necessary to specify not only the intensity but also the quality of the light emitted. The fact that the inertia value obtained depends upon the quality of the light to which the plate is exposed offers a very convenient means of measuring the relative photographic efficiencies of different illuminants.

In testing plates for speed the light source is kept constant in quality and intensity, and the reciprocal of the inertia value obtained is proportional to the speed of the plate. Now, if the plate speed be kept constant and the quality of the light changed by using different sources, the reciprocals of the resulting inertia values may be taken as directly proportional to the relative photographic efficiencies of the various sources.

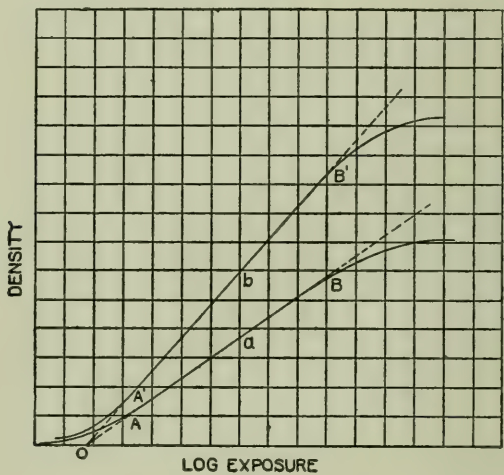


Fig. 1.

Suppose that using source A an inertia value of i_1 is obtained, and with another source B the inertia is i_2. Then the photographic efficiency of B relative to that of A will be $\frac{i_1}{i_2} \times 100$.

Obviously, in making such a comparison it is necessary to choose some source to be used as a standard. Since in practical work a great majority of the plates used are exposed to light from the sun, it seems most logical to adopt that as the standard of quality by which to judge all artificial illuminants. Some may contend that daylight or north skylight would be more suitable and

nearer to actual practise as a standard of quality. Daylight is a mixture of sunlight and skylight in some indefinite and variable proportion, and skylight is likewise indefinite in quality and not reproducible. Sunlight, on the other hand, if taken between 9 A. M. and 3 P. M. on a clear day, is of a very definite quality. For these reasons sunlight has been chosen as a standard of quality, and its photographic efficiency on any plate is taken to be 100 per cent.

APPARATUS.

The sensitometer used in this work is of the "falling plate" type. An aluminum plate in which a series of openings of varying lengths are cut moves up and down between a pair of ways. This plate is driven at a very uniform rate by a constant-speed governed motor. The openings in the plate increase in length by powers of $\sqrt{2}$ so that a sensitive plate placed behind it in a suitable dark slide will receive a series of exposures increasing by consecutive powers of $\sqrt{2}$; thus, twice as many points are obtained as in the usual type of sensitometer, allowing the characteristic curve to be more precisely located and, hence, the inertia value more definitely determined. The rate at which the falling plate moves is very constant and is so precisely known that the time of exposure can be determined to within ± 0.2 per cent. In order to measure the illumination on the photographic plate a means is provided by which a modified Lummer-Brodhun photometer head may be inserted in place of the dark slide, the photometer screen occupying the same plane as the photographic plate when in position for exposure. One side of the photometer screen is illuminated by a small electric glow lamp carefully seasoned and controlled to constant current by potentiometer method. This lamp is mounted on a small carriage moving on a pair of rails, with scale and index. The scale was calibrated by means of a standard glow lamp set at varying distances from the other side of the photometer screen. Thus it is possible to measure very accurately the illumination incident on the photographic plate.

The sensitometer is mounted on a pair of rails running along the top of a table extending down the side of the photometer room. At one end of this table is the photometer bench on which

is mounted a three meter photometer of the National Physical Laboratory type. The rails carrying the sensitometer are lined up in such a way that as the instrument is moved along the ways, the plate holder containing the plate to be exposed remains always on the photometric axis of the bench photometer. The light source to be tested is mounted on the photometer and by moving the sensitometer along the rails the distance between the plate and source can be adjusted, as desired, to any value up to twelve meters.

The sensitometer is provided with a set of gears so that the falling plate can be driven at various velocities. The highest velocity of movement gives an exposure of two and one-half minutes to that portion of the plate behind the longest slot. It was found that for medium speed plates and with the machine running at its highest velocity that an illumination of 0.1 meter candle on the plate gave the proper exposure for the production of a complete characteristic curve. Hence, an illumination of 0.1 meter candle was adopted as standard.

The distance available (12 meters) is only sufficient to make possible the use of sources running up to an intensity of 14.4 candlepower; therefore, in order to test high candlepower sources such as the 1,000-watt gas-filled lamps, it was necessary to devise some means of reducing their intensity without altering the quality of the light. A rotating sector cannot be used on account of the danger of introducing errors due to the intermittency of the exposure given to the photographic plate. Various absorbing and diffusing screens were tried but none were found sufficiently non-selective to permit of their being used in work of this kind. Finally, a lens system was tried and found to be very satisfactory for the purpose.

Two lenses of short focal length are mounted so as to move along the photometric axis. The one nearest to the source is so placed that an image of the source is formed at the principle point of the other lens—the one nearest to the sensitometer. This arrangement gives a very uniformly illuminated field, readily adjustable to any intensity by varying either the focal lengths of the lenses used or the distance from the source to the first lens.

The lenses used for this purpose are made either of a clear

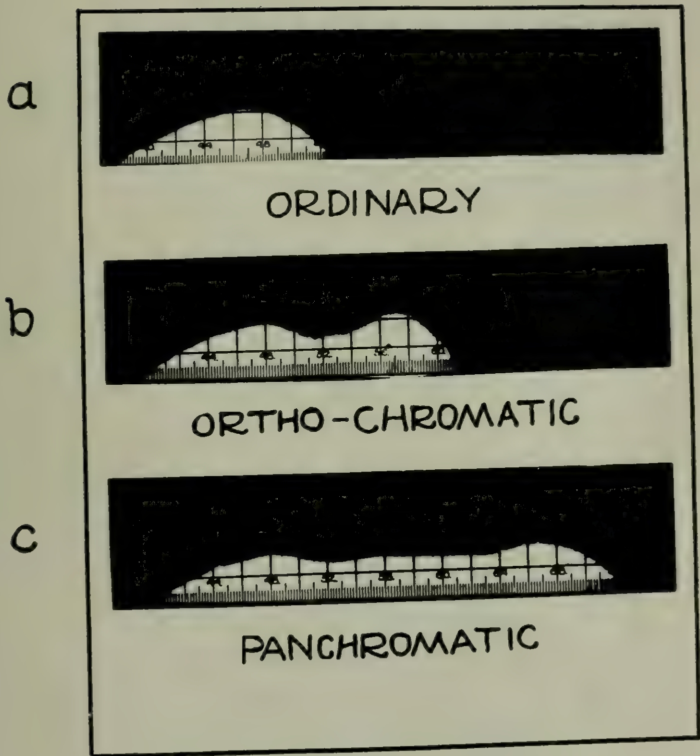
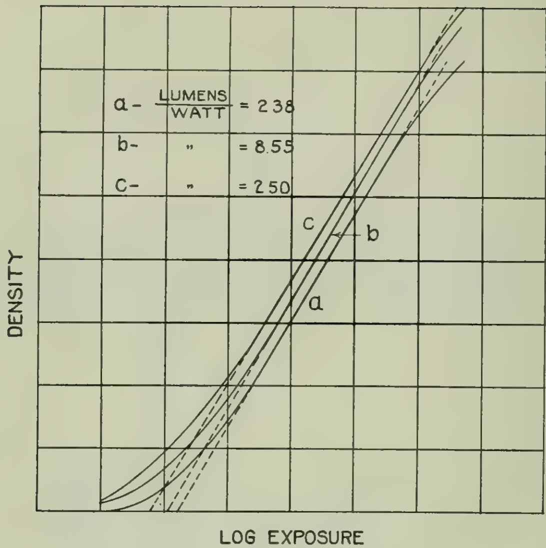
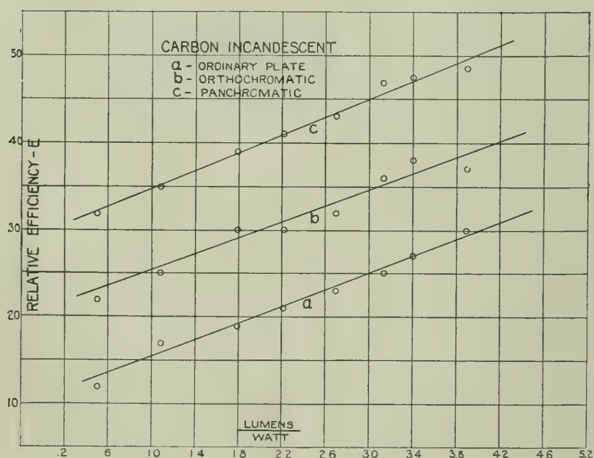


Fig. 2.—Spectral sensibilities of photographic materials.



a - LUMENS/WATT = 2.38
b - " = 8.55
c - " = 2.50
c
b
a
DENSITY
LOG EXPOSURE

Fig. 3.



CARBON INCANDESCENT
a - ORDINARY PLATE
b - ORTHOCHROMATIC
c - PANCHROMATIC
RELATIVE EFFICIENCY - E
LUMENS/WATT

Fig. 4.

white crown glass or of quartz. All reduction of intensity, then, is made either by increasing the distance or by use of lenses, and thus any change in the quality of the light is avoided. Since the sensitometer is of the falling plate type the exposures are always continuous, and all danger of intermittency errors is avoided.

The photometric measurements were made on the bench photometer. The head is of the ordinary Lummer-Brodhun type and the standards used are certified by the Bureau of Standards and by the National Physical Laboratory. These standards were operated on a storage battery and controlled by the potentiometer method. The electric sources used were operated, when possible, from the storage cells and controlled by potentiometer or by reliable Weston volt and ammeters. Measurements involving a difference in color were made directly without the aid of compensating filters or a flicker photometer. Readings were made by two experienced observers, and errors occurring due to a lack of color match are undoubtedly much less than those due to other factors involved in the sensitometric measurements.

The measurements of density were made by means of a Martens polarization photometer, the plates being placed with the emulsion side in contact with an opal glass diffusing screen so that the values obtained were for the diffuse density of the deposit.

PHOTOGRAPHIC MATERIALS.

Photographic materials used for negative making, classified with respect to the spectral sensibility, fall into three distinct groups; ordinary, orthochromatic and panchromatic.

The first of these, the ordinary, is sensitive only to violet, blue and blue-green, the maximum occurring at about $460\mu\mu$. This is shown by the photograph reproduced in Fig. 2, which is a spectrum photograph made on an ordinary plate (Seed 23) by exposure to an acetylene flame. The photograph was made in a grating spectrograph in front of the slit of which was placed a neutral gray wedge, thus causing the intensity to decrease logarithmically from one end of the slit to the other. The curve outlined by the dark portion is, therefore, the resultant of the

spectral sensibility curve of the plate and the spectral energy curve of the source—in this case an acetylene flame.

Materials of the second class, orthochromatic, are sensitive to blue and yellow-green, as is shown in Fig. 2, this being a spectrum photograph made on an orthochromatic plate. In this case a second maximum occurs in the yellow-green at about $560\mu\mu$.

The third class of materials, panchromatic, is sensitive to practically the entire visible spectrum; Fig. 2 shows a photograph made on a Wratten panchromatic. The panchromatic plates were used in this work without the interposition of a colored screen between the source and the plate. In practise, these plates are, as a rule, used with a filter of such nature that the resultant spectral sensibility of the plate is very nearly the same as the visibility curve of the eye, thus giving correct rendering to the different colors in the subject being photographed. Under such conditions, with the filter adjusted to the plate and source, the relative photographic efficiency, E_r, of any source is approximately 100.

One plate typical of each class was chosen for use in this work; each is of medium speed and is a good average representative of its group. Those used are:

a. Ordinary—Seed 23.
b. Orthochromatic—Special experimental plate.
c. Panchromatic—Wratten panchromatic.

SOURCES.

1. *Sunlight.*—A heliostat was placed outside a window at the end of the photometer bench and a beam of sunlight reflected inward along the axis of the photometer. The heliostat mirror is of clear white optical glass, silvered on the back surface. The illumination incident on the photographic plate was reduced to 0.1 meter candle by crown glass lenses. The exposures were made between 1.30 and 2.30 P. M. on a clear day.

2. *Skylight.*—The heliostat mirror was set in such a position that by looking down the photometric axis a portion of the sky near the zenith could be seen. The window was then closed by a diaphragm which allowed no light except that reflected from the mirror to enter the room. Glass lenses were used to reduce the intensity. Exposures were made between 2.30 and 3.00 P. M. on a clear day.

3. *Acetylene*.—A standard acetylene burner of the type previously described was used. The flame is of the cylindrical type and is screened down to give approximately 1.3 candlepower.

4. *Screened Acetylene*.—The above source was screened with a blue filter of such quality that the transmitted light matches very closely the color of average daylight.

5. *Pentane*.—A standard Harcourt pentane lamp was used, being adjusted in accord with standard specifications.

6. *Mercury Arc*.—A 200-250 volt quartz mercury arc running at 220 volts and 3.4 amperes was used. A reflector consisting of a highly polished plate of black glass 2 cm. thick was employed in this case. All the light utilized was reflected from the first surface (air-glass), such reflection being considered to be very non-selective. The intensity was reduced by a pair of quartz lenses.

7. *Mercury Arc*.—The above source was screened with a piece of heavy lead glass 4 mm. thick, sold under the trade name of "Nultra" and recommended for use in the absorption of the ultraviolet rays. This glass is quite colorless and transparent, the sample used having a transmission (measured visually) of about 90 per cent.

8. *Mercury Arc*.—The conditions were the same as described under No. 6, the one exception being that a clear white crown glass lens was substituted for one of the quartz lenses used previously.

9. *Carbon Arc, Open*.—An automatic feed arc, with carbons at right angles, was used for this test. The positive carbon was coincident with the photometric axis, the crater facing the sensitometer. The arc was operated on 110 volts, d. c., and a current of 6 amperes was used. The drop across the arc was about 60 volts. The positive carbon was about 6 mm. in diameter and was cored. Intensity was reduced by glass lenses.

10. *Carbon Arc, White Flame Carbons*.—A 115 volt d. c. arc with a 10 mm. white flame carbon below and a 13 mm. cored carbon above. The arc was connected so as to make the lower carbon + and was mounted in such a way that the flame, which was about 2.5 to 3 cm. long, occupied a position on the photometric axis. The intensity was reduced by means of one quartz and one

crown glass lens. The voltage across the arc was about 85 volts and the current 24 to 26 amperes.

11. *Enclosed Arc.*—In this case the arc was enclosed in a glass cylinder provided with close fitting metal ends. The carbons were of the ordinary cored type, placed at right angles to each other, the positive crater being on the photometric axis and facing the sensitometer. It was run on 110 volts, d. c., and consumed 8 amperes, the drop across the arc being 65 volts.

12. *Aristo Arc.*—This was an enclosed arc with carbons vertical, positive above. It was operated on 220 volts, d. c., and consumed 16 amperes. The length of arc was approximately 2.5 cm.

13. *Magnetite Arc.*—This was of the ordinary commercial type running on 110 volts, d. c., and using a current of 4 amperes. Intensity was reduced by glass lenses.

14. *Carbon Glow Lamp.*—For these tests a 50-volt lamp with hairpin type filament, giving 16 cp. at normal voltage was used. Tests were made at several points, beginning at 1 cp. and running up to 21 cp. The m. h. cp. was determined by the point to point method and a reduction factor of 0.79 was assumed for obtaining the mean spherical candlepower.

15. *Vacuum Tungsten.*—A 120 volt, 10 watt lamp or the ordinary commercial type was used. Reduction factor = 0.78.

16. *Nitrogen-filled Tungsten.*—A 120 volt, 400 watt lamp was employed, tests being made at various points between 59 and 130 volts. Reduction factor = 0.86.

17. *Photolite Tungsten, Blue Glass Bulb.*—A 120 volt, 1,000 watt G. E. photolite was used, being operated at various voltages from 55 up to 134. Reduction factor = 0.88.

18. A *mercury-vapor arc* in a glass tube 45 x 2.8 cm. was used. The tube was operated on 115 volts d. c., the drop across the tube being 33 volts with a current of 3.5 amperes. The tube was mounted so as to intersect the photometric axis at an angle of 90° and a diaphragm being so placed that a section of the tube 2 cm. long midway between the ends of the tube and on the photometric axis was used in exposing the plates.

EXPERIMENTAL DETAILS AND ERRORS.

In exposing the plates the source to be tested was placed on the photometer and conditions so adjusted that the illumination

on the plane of the photographic plate was 0.1 meter-candle. For sources under 14.4 cp. this was done by computing from the known candlepower the distance required and setting the position of the sensitometer accordingly. For sources of greater intensity the reducing lenses were placed in position and the sensitometer adjusted to such a position that the required illumination was obtained. This was determined by readings taken on the illuminometer attached to the sensitometer, the probable error of the value thus determined being approximately ± 2 per cent. A light tight partition separated the source and photometric apparatus from the portion of the room containing the sensitometer, an opening on the photomertic axis admitting light from the source to the photographic plate. Screening diaphragms placed at proper intervals prevented any stray light from reaching the plate, while being exposed. All walls and ceilings were painted dead black to prevent reflections.

The photographic plates were backed in order to prevent halation and development was done with a standard pyro-soda developer used at a fixed temperature, 70° F. The plates were developed in a tray which was rocked continually by hand during development. This method has been found to give the most satisfactory results where uniformity of development is desired.

Three to six plates were exposed under each condition and the average of the inertia values obtained was used in calculating the photographic efficiency.

The experimental error liable to occur in work involving the sensitometry of photographic materials are numerous and rather large. By using a "falling plate" sensitometer all possibility of errors due to an intermittent exposure was eliminated. Errors arising from a failure of the reciprocity law were eliminated by keeping constant the exposure time and the illumination on the plate. The exposure times were determined to within ± 0.2 per cent. and the illumination on the plate to within ± 2.0 per cent. Variations due to lack of uniformity of coating and to inequalities in sensitiveness may in some cases amount to as much as 20 per cent. from plate to plate. However, by making several exposures and averaging the results the uncertainty can be reduced to a probable error of about ± 5 per cent. The total probable error

in values given in this paper is estimated at approximately ±7 per cent.

RESULTS.

In Fig. 3 are shown three curves obtained from three groups of plates (Seed 23) exposed to a nitrogen filled tungsten lamp operated at three efficiencies. The exposure was the same in all cases and the shift in the inertia value indicates the increase in photographic efficiency corresponding to the increase in visual efficiency at which the lamp was operated. In Table I are given the data obtained from the individual plates of the group from which curve A, Fig. 3, was plotted. This table of data is presented merely to show the order of agreement that can be expected in work of this nature.

TABLE I.

Step	Exposure M. C. S.	Density No. 108	No. 109	No. 110	No. 111	Mean
1	0.06	0.0	0.0	0.0	0.0	0.0
2	0.08	0.01	0.0	0.02	0.03	0.02
3	0.12	0.05	0.03	0.09	0.08	0.08
4	0.17	0.16	0.12	0.17	0.16	0.15
5	0.24	0.30	0.27	0.27	0.26	0.27
6	0.34	0.46	0.43	0.42	0.41	0.43
7	0.47	0.68	0.63	0.63	0.58	0.61
8	0.67	0.92	0.87	0.86	0.83	0.87
9	0.94	1.20	1.14	1.10	1.09	1.13
10	1.33	1.43	1.32	1.43	1.29	1.37
11	1.88	1.73	1.60	1.60	1.57	1.62
12	2.66	1.97	1.83	1.87	1.82	1.87
13	3.75	2.29	2.13	2.10	2.10	2.16
14	5.31	2.72	2.38	2.45	2.48	2.51
15	7.50	2.96	2.91	2.91	3.16	2.98
16	10.60	—	—	—	—	—
17	15.00	—	—	—	—	—
	Log i	0.33	0.32	0.35	0.33	0.332
	i	0.214	0.209	0.229	0.214	0.216
	S	4.67	4.79	4.37	4.67	4.62

The results obtained from the exposures made to sunlight are as follows:

On Seed 23 (ordinary blue sensitive)

$$\log i = \bar{2}.86$$
$$i = 0.0725$$
$$\text{Sensitiveness} = \frac{1}{i} = 13.8.$$

On Experimental Ortho. (orthochromatic)

$$\log i = \bar{2}.71$$
$$i = 0.0513$$
$$\text{Sensitiveness} = \frac{1}{i} = 19.5.$$

On Wratten panchromatic (panchromatic)

$$\log i = \bar{2}.796$$
$$i = 0.0625$$
$$\text{Sensitiveness} = \frac{1}{i} = 16.0.$$

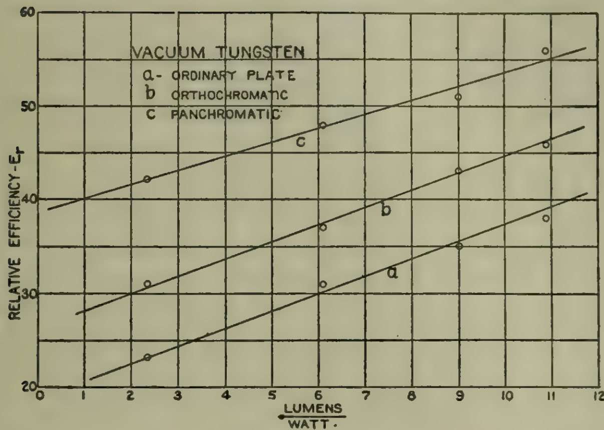


Fig. 5.

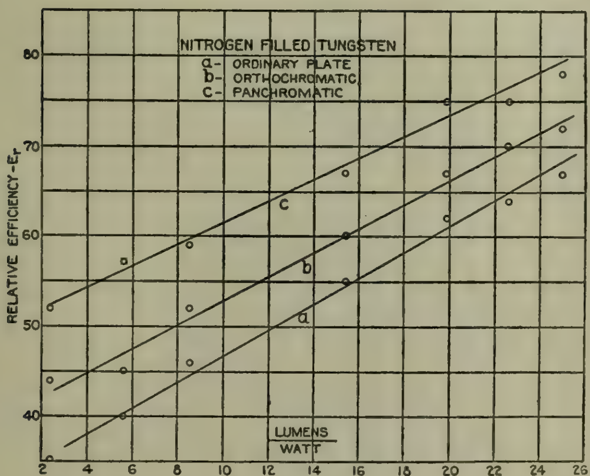


Fig. 6.

Since sunlight is used as a standard of comparison in this work, its efficiency on each plate is assumed to be 100 per cent. and the relative photographic efficiency of any illuminant is obtained by

taking the ratio (x100) of the sensitiveness value $\frac{1}{i}$ obtained with that source on a given plate, to that obtained with sunlight on the same plate. This ratio is termed the relative photographic efficiency and is designated by the symbol, E_r. Therefore, if the relative efficiency E_r of a source is 50 per cent., in order to obtain a given effect on a photographic plate twice as great an exposure (measured in meter candle seconds) must be given when using that source as would be required in case sunlight were used.

In Table II is given a complete set of data obtained by using a nitrogen filled tungsten lamp at various efficiencies on an ordinary blue sensitive (Seed 23) plate. Four plates were exposed at each efficiency and the individual log i values are given in the table, the E_r values being computed from the mean of each group. The agreement between the log i values in this set is somewhat better than the average with the exception of the third group. In this group (at 9.67 lumens per watt) the maximum deviation from the mean of the inertia values is $+22$ per cent. This is much greater than the average deviation existing and can only

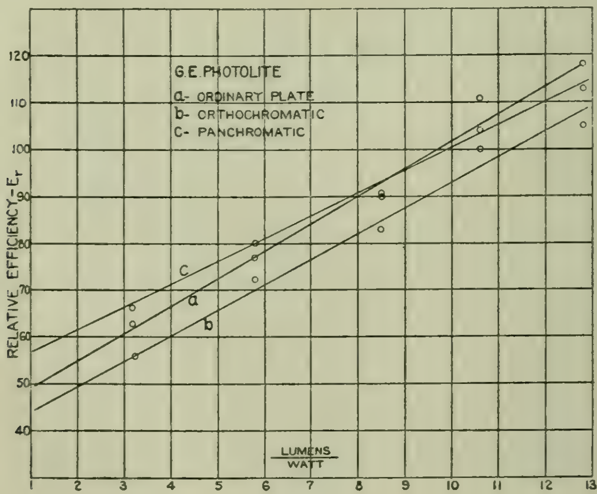


Fig. 7.

be ascribed to inequalities of coating or sensitiveness, since all other errors are known to be less than ± 5 per cent.

TABLE II.

Source—Nitrogen-filled tungsten.
Watts, 400.
Volts, 120.
Reduction factor, 0.88.
Plate—Seed 23 (Ordinary, blue sensitive).
Exposure—Meter-candle seconds = 15.0.
Illumination on plate = 0.10 m.c.
Time = 150 sec.

Photometric data				Sensitometric data			
Volts	Amps.	M.h.cp.	$\frac{\text{Lumens}}{\text{Watt}}$	Log i		$\frac{1}{i}$	E_T
				0.33			
				0.32			
				0.35			
				0.33			
59	2.42	30.8	2.38	M 0.33	0.214	4.67	34
				0.26			
				0.26			
				0.26			
				0.27			
78	2.81	111.0	5.61	M 0.26	0.182	5.50	40
				0.29			
				0.15			
				0.20			
				0.18			
95.6	3.12	274.0	8.55	0.20	0.160	6.25	45
				0.10			
				0.13			
				0.12			
				0.12			
110	3.34	514.0	15.4	0.12	0.132	7.58	55
				0.06			
				0.07			
				0.06			
				0.08			
120	3.52	760.0	19.9	0.07	0.117	8.55	62
				0.06			
				0.05			
				0.05			
				0.05			
125	3.61	920.0	22.6	0.05	0.112	8.93	65
				0.03			
				0.03			
				0.03			
				0.05			
130	3.66	1080.0	25.0	0.03	0.107	9.35	68

In Tables III to VI, inclusive, are given the summarized results on glow lamps, as follows:

Table III—Carbon from 0.5 to 3.8 lumens/watt.
Table IV—Tungsten from 3.23 to 10.9 lumens/watt.
Table V—Nitrogen tungsten from 2.48 to 23.8 lumens/watt.
Table VI—Nitrogen filled blue bulb Photolite, 1.00 to 12.8 lumens/watt.

The data on these sources are given as curves in Figs. 4, 5, 6 and 7. The curves obtained are all straight lines within the limits of experimental errors and over the ranges of efficiencies used.

TABLE III.

Source—Carbon glow lamp.
Volts, 45.
Watts, 40.
Reduction factor, 79.
Exposure—15.0 meter-candle seconds.
Illumination = 0.10 m.c.
Time = 150 sec.

Visual eff. lumen watt	Photographic material: Ordinary S	Ordinary E_r	Orthochromatic S	Orthochromatic E_r	Panchromatic S	Panchromatic E_r
0.51	1.7	12	4.2	22	5.1	32
1.09	2.2	17	4.8	25	5.6	35
1.79	2.6	19	5.9	30	6.2	39
2.25	2.8	21	5.9	30	6.6	41
2.70	3.1	23	6.2	32	6.9	43
3.14	3.4	25	7.0	36	7.5	47
3.41	3.7	27	7.4	38	7.5	47
3.90	4.1	30	7.2	37	7.7	48

TABLE IV.

Source—Tungsten glow lamp.
Watts, 10.
Volts, 120.
Reduction factor, 78.
Exposure—15 meter-candle seconds.
Illumination = 0.10 m.c.
Time = 150 sec.

Visual eff. lumen watt	Photographic material: Ordinary S	Ordinary E_r	Orthochromatic S	Orthochromatic E_r	Panchromatic S	Panchromatic E_r
2.33	3.1	23	6.05	31	6.7	42
6.09	4.3	31	7.2	37	7.8	48
9.00	4.8	35	8.4	43	8.2	51
10.9	5.2	38	8.9	46	9.0	56

TABLE V.

Source—Nitrogen-filled tungsten.
Watts, 400.
Volts, 120.
Reduction factor 88.
Exposure—15 meter-candle seconds.
Illumination, = 0.10 m.c.
Time = 150 sec.

Visual eff. lumens watt	Photographic material: Ordinary S	Ordinary E_r	Orthochromatic S	Orthochromatic E_r	Panchromatic S	Panchromatic E_r
238.0	4.8	35	8.6	44	8.3	52
5.61	5.0	40	8.8	45	9.1	57
8.55	6.3	46	10.1	52	9.4	59
15.4	7.5	55	11.7	60	10.7	67
19.9	8.6	62	13.0	67	12.0	75
22.6	8.8	64	13.6	70	12.0	75
25.0	9.2	67	14.0	72	12.5	78

TABLE VI.

Source—Nitrogen-filled, blue glass bulb.
Watts, 1,000.
Volts, 120.
Reduction factor, 86.
Exposure – 15 meter-candle seconds.
Illumination = 0.10 m.c.
Time = 150 sec.

Visual eff. lumen watt	Photographic material: Ordinary S	Ordinary E_r	Orthochromatic S	Orthochromatic E_r	Panchromatic S	Panchromatic E_r
0.9	6.8	49	8.4	43	9.0	56
3.22	8.7	63	10.9	56	10.6	66
5.81	10.6	77	14.1	72	12.8	80
8.48	12.4	90	16.2	83	14.6	91
10.6	15.3	111	19.5	100	16.6	104
12.8	16.3	118	20.5	105	18.1	113

The results obtained with other illuminants are summarized in Table VII. The visual efficiencies of some were not measured in this laboratory. In such cases the available data on the subject were consulted and from them an estimate of the efficiency existing under the conditions of operation employed in this work was made, such values being indicated by stars.

TABLE VII.

Source	Visual efficiency lumens watt	Photographic materials: Ordinary S	Ordinary E_r	Ortho-chromatic S	Ortho-chromatic E_r	Pan-chromatic S	Pan-chromatic E_r
1. Sun	*150.0	13.8	100	19.5	100	16.0	100
2. Sky	—	25.0	181	30.0	155	21.0	130
3. Acetylene	*0.7	4.1	30	8.6	44	8.3	52
4. Acetylene screened	*0.07	11.2	81	16.5	85	14.2	89
5. Pentane	*0.45	2.5	18	5.5	28	6.7	42
6. Mercury arc—quartz	*40.0	83.0	600	98.0	500	59.0	367
7. Mercury arc—nultra glass	*35.0	30.0	218	38.0	195	26.4	165
8. Mercury arc—crown glass	*37.0	44.7	324	53.7	275	39.8	249
9. Carbon arc—ordinary	*12.0	17.4	126	22.0	112	17.0	104
10. Carbon arc—white flame	*29.0	35.5	257	46.5	234	34.4	215
11. Carbon arc—enclosed	*9.0	24.2	175	34.5	177	26.4	165
12. Carbon arc—"Aristo"	*12.0	110.0	796	209.0	1,070	119.0	744
13. Magnetite arc	*18.0	14.6	106	22.4	115	13.1	82
14. Carbon glow lamp	2.44	3.2	23	6.2	32	6.7	42
Carbon glow lamp	3.16	3.4	25	6.8	35	7.2	45
15. Tungsten evacuated	8.0	4.6	33	8.0	41	8.0	50
Tungsten evacuated	9.9	5.1	37	8.8	45	8.5	53
16. Tungsten nitrogen-filled	16.6	7.7	56	12.1	62	11.2	70
Tungsten nitrogen-filled	21.6	8.8	64	13.3	68	12.2	76
17. Tungsten blue bulb	8.9	13.1	95	17.0	87	15.2	95
Tungsten blue bulb	11.0	15.0	108	19.3	99	17.0	106
18. Mercury-vapor	*23.0	42.7	316	69.0	354	43.7	273

As previously stated the values of E_r given in Table VII are relative values and do not express the photographic efficiencies of the various sources in terms of the energy consumption of that source. As the efficiency in terms of energy consumption is of considerable interest the values obtained have been reduced to that basis and are given in Table VIII.

The inertia values (i) obtained from the characteristic plate curves are expressed in exposure units, that is, meter-candle seconds. The luminous flux incident upon unit area (1 square cm.) at a meter distant from a source of 1 mean spherical candle-power is $\frac{4\pi}{4\pi r^2} = \frac{1}{100^2}$ lumens. This is the value of the luminous flux incident upon a unit area of a surface at which the illumination is 1.0 meter-candle. Then

$$i_e = \frac{i \text{ (in m. c. s.)}}{100^2} \text{ is the inertia value}$$

$$\text{expressed in } \frac{\text{lumens seconds}}{\text{cm.}^2}.$$

TABLE VIII.

Source	Efficiency lumens/watt	Photographic materials: Ordinary i_e	Ordinary E_e	Orthochromatic i_e	Orthochromatic E_e	Panchromatic i_e	Panchromatic E_e
1. Sun	150.0	0.473	100.0	0.342	100.0	0.417	100.0
2. Sky	—	—	—	—	—	—	—
3. Acetylene	0.7	348.0	0.14	166.0	0.21	172.0	0.24
4. Acetylene screened	0.07	1,275.0	0.04	865.0	0.040	1,000.0	0.042
5. Pentane	0.45	888.0	0.05	400.0	0.9	330.0	0.13
6. Mercury arc—quartz	40.0	0.30	158.0	0.26	130.0	0.42	99.0
7. Mercury arc—"nultra"	35.0	0.95	50.0	0.75	47.0	1.08	39.0
8. Mercury arc—crown	37.0	0.61	79.0	0.50	68.0	0.68	62.0
9. Carbon arc—ordinary	12.0	4.8	10.0	3.8	9.0	4.9	8.5
10. Carbon arc—white flame	29.0	0.92	52.0	0.76	45.0	1.0	42.0
11. Carbon arc—enclosed	9.0	4.6	11.0	3.2	11.0	4.2	10.0
12. Carbon arc—"Aristo"	12.0	0.76	62.0	0.40	86.0	0.70	60.0
13. Magnetite arc	18.0	3.0	12.0	2.5	14.0	4.2	10.0
14. Carbon glow	2.44	128.0	0.37	66.0	0.52	61.2	0.68
Carbon glow	3.16	93.2	0.51	46.5	0.74	44.0	0.95
15. Tungsten vacuum	8.0	27.2	1.7	15.6	2.2	15.6	2.7
Tungsten vacuum	9.9	19.8	2.4	11.5	3.0	11.9	3.50
16. Tungsten-nitrogen	16.6	7.8	6.1	5.0	6.8	5.4	7.7
Tungsten-nitrogen	21.6	5.3	8.9	3.5	9.8	3.8	11.0
17. Tungsten blue bulb	8.9	8.6	5.5	6.6	5.2	7.4	5.6
Tungsten blue bulb	11.0	6.1	7.8	4.7	7.31	5.3	7.9
18. Mercury-vapor	23.0	1.0	47.0	0.63	54.0	1.0	42.0

Now, if the efficiency of the source used is E $\left(\text{in } \frac{\text{lumens}}{\text{watt}}\right)$ the value remains the same when expressed in $\frac{\text{lumen seconds}}{\text{watt second}}$, $\frac{1}{E}$ is the efficiency in $\frac{\text{watt seconds}}{\text{lumen seconds}}$, and

$$i_e = \frac{i \text{ (in m. c. s.)}}{100^2} \times \frac{1}{E} = \frac{\text{watts seconds}}{\text{cm.}^2},$$

$$i_e = \frac{i \text{ (in m. c. s.)}}{100^2} \times \frac{10^7}{E} = \frac{\text{ergs}}{\text{cm.}^2}.$$

i_e is, therefore, the inertia value expressed in ergs consumed at the source per cm.² at the plate. This value is inversely proportional to the photographic efficiency of the source when used on that particular plate. The photographic efficiency may be obtained, therefore, by taking the reciprocal of i_e.

In order to make the results obtained on different plates comparable with each other it is necessary to use some source as a standard. Sunlight is used as before, its efficiency being taken as 100 on each plate.

The values of visual efficiency for many sources were not measured directly, but were estimated from the last available data found in the literature on the subject. The values tabulated in Table VIII are:

$$i_e = \frac{i \text{ (m. c. s.) } 10^3}{E} = \frac{\text{ergs}}{\text{cm.}^2},$$

$$E_e = \frac{1{,}000\ i_e \text{ (for sun)}}{i_e \text{ (for particular source)}}.$$

It will be noted by reference to the curves in Figs. 4, 5 and 6 that the curves of relative efficiency are straight lines slightly convergent toward the higher efficiencies. The curve for the orthochromatic material lies about midway between the other two in each case. In the case of the gas-filled lamp with blue bulb the curves for the ordinary and the panchromatic materials converge and cross at $E_r = 95$ per cent., while the ortho curve is entirely below them. This is due to the fact that the glass of which the bulb is made has an absorption band in the green, the region of extreme sensitiveness for orthochromatic materials. The light emitted is, therefore, relatively weak in the green and

as a consequence gives low efficiencies on orthochromatic materials.

The values of E_r given in Table VII enable us to pick from any group of sources the one giving the greatest photographic efficiency when used in connection with either of the three typical classes of photographic materials, for a fixed value of the *illumination*. The values in Table VIII, on the other hand, enable us to choose for either class of materials, the source that is most efficient photographically, from the standpoint of *energy consumption*.

The choice of a source for any particular purpose frequently depends on factors other than efficiency, but no attempt is made in this paper to deal with such cases.

Other photographic materials such as wet plates, printing papers and processes depending upon the sensitiveness of bichromate involving different spectral sensibilities have not been dealt with in this paper. The authors hope at some future time to extend the measurements to cover such cases and also some other illuminants not dealt with at this time.

The authors wish to acknowledge their indebtedness and to express their thanks to Mr. R. B. Wilsey for his able assistance rendered in connection with the experimental work involved in this research.

DISCUSSION.

MR. M. LUCKIESH: I want to compliment the authors for this excellent summary and also to point out the fact that there are other important viewpoints from which to consider an illuminant for photographic purposes. We, as lighting people, are inclined to apply ordinary lighting criteria and ideals to the photographic field, but it is easy to show this is not justifiable. I also want to call attention to the fact that the so-called efficiencies of illuminants for photographic processes must be considered a good deal as we should consider efficiencies in lighting; that is, the element of satisfactoriness must enter which is determined by many factors besides the photographic efficiency given here. This discussion is not presented to detract from the value of this excellent work but to emphasize the other viewpoints so that

the illuminating engineers will not overlook these facts and assume that the illuminants from a practical standpoint lie in the order given here because they do not. I am glad the authors include Tables VII and VIII because in much of the photographic field, energy consumption (or photographic efficiency given in Table VIII) is of minor importance provided it is within reasonable bounds. Of more importance is Table VII because it is necessary to have a light of high actinic value per lumen in order to obtain portraits with short exposures and without glare. In the portrait studios it takes only a few minutes to do the posing and make the exposure so it is seen that other factors may easily over-shadow photographic efficiency (actinic value per watt). Even in the moving picture studios where excessive wattages are used, it has been found that energy consumption is far from being the most important factor. Actinic value per lumen, cost, portability, simplicity, color, etc., are factors of great importance to those who use photographic illuminants especially in portraiture and moving picture production.

I am pleased to note that the authors have checked my measurements given for the gas-filled tungsten lamps. Throughout my work in converting the gas-filled tungsten lamp (TRANS. I. E. S., Vol. X, No. 2, p. 149) into an acceptable unit for the portrait photographers, the kind of plate used was of great importance. The ordinary plate which is used very predominantly in portraiture was the determining factor in the development of this photographic tungsten lamp. Of course it is the photochemists' dream that some day the panchromatic plate will be in general use and that this plate will be cheap, efficient, and capable of recording brightnesses in the same relative value as the eye sees them. That may be the ideal but it is far from realization, so that the ordinary plate must be recognized as the determining factor in dealing with the practise of photography in general. This was done in the development of the blue bulb for the photographic tungsten lamp and therefore it is most efficient for these plates. In Table VII, the light from this unit is seen to be comparable with daylight in actinic value. Another point of importance is the color of this light. It is a close match to daylight when considered integrally. It does not match day-

light spectrally, but this is of no importance for ordinary plates. The fact that this light is approximately of the color and actinic value of daylight has proved to be highly in its favor because of the possibility of using it combined with daylight. Incidentally, this illuminant is satisfactory for orthochromatic or panchromatic plates and for color-photography for orthochromatic or panchromatic plates and for color-photography because all rays are present in its spectrum although it is less efficient for these processes.

I want to emphasize that it is necessary to distinguish between the photographic process and the visual process, as the authors have done, and that in dealing with photography we are dealing with a lot of 'eyes' that differ from each other a great deal more than normal eyes differ from each other, and that these photographic 'eyes' are in general tremendously different in sensibility from the human eye. That means that we must alter our criteria for judging illuminants for photographic purposes. For instance, the life which may be considered the most economical for an electric incandescent lamp for ordinary lighting service will not be the most economical for a photographic unit. The authors have taken, no doubt, the incandescent lamps operated at their normal efficiencies which are determined by ordinary lighting service and the human eye. When we use photographic units a few minutes now and a few in the next hour, we can boost the efficiency up and the life down very considerably, and approach a more economical operating point for an incandescent lamp. As I have shown in my papers on the subject, a slight increase in voltage causes a much greater increase in the actinic value of the light from the tungsten lamp for ordinary plates, with an accompanying reduction in life; however, by increasing the voltage, we have approached the most economical point at which to operate these lamps for photographic purposes.

In order to avoid confusion I wish to distinguish between two units, namely, actinic value per lumen and actinic value per watt. The relation between these two units is fairly definite (if the photographic process is specified) for a given illuminant but the relation differs with each illuminant. Therefore, in general there is no relation between the two units.

MR. L. A. JONES: In regard to Mr. Luckiesh's point concerning other considerations coming in for photographic work, I think the point is very well taken. As stated in the paper, we do not attempt to cover all the points of advantage and disadvantage in the various sources; but only treat the subject from the standpoint of illumination and energy; also, I might add, there are a great many other photographic materials having different spectral-sensibilities which we have not treated here, such as wet plates, bichromated gelatine, etc. In regard to the question as to the Aristo arc and white flame—I believe that has been answered very satisfactorily. The Aristo lamp was an enclosed arc burning hard carbons and the white flame was an arc equipped with the ordinary white flame photographic carbons burning open. In regard to the quartz lamp, No. 6, the intensity in that case was reduced by means of quartz lenses, as I believe is stated in the paper. No. 7 was shielded by means of a piece of lead glass designed and sold as an absorber of the ultra-violet, while in the case of No. 8, thre same arc was used with the exception that a piece of crown glass, such as is used in making photographic lenses, was substituted, in place of the lead glass. Of course, the efficiency given in No. 6 could never be realized in case a glass lens is used in the camera, while the efficiency of No. 8 is the efficiency that would be realized in case a camera with a crown glass lens were used. No. 18 is the Cooper-Hewitt glass tube mercury-vapor arc. In regard to the term "falling plate" as descriptive of the sensitometer used, I probably failed to clearly define its meaning. The term is used among workers in photographic sensitometry to differentiate between the class of sensitometer in which the exposure is continuous, and those in which the exposure is intermittent, as is the case when a rotating sector is used. As a previous speaker has pointed out it is not the photographic plate which moves, but a metal plate in which apertures of varying lengths are cut. This plate travels at a uniform rate between the photographic plate and the light source.

GENERAL REPORT ON GLARE.*

Synopsis: The work of the committee the past year is summarized. Tentative definitions are offered of different classes of glare and the phenomenon of glare is analyzed and defined with as much precision as seems possible at the present time. Limits of tolerance of the eye to brightness conditions above which limits glare may be said to exist are stated as definitely as possible. The twelve reports supplementary to this general report of the committee are briefly outlined.

INTRODUCTION.

The word glare has been commonly used since the beginning of illuminating engineering and its general meaning is fairly well understood. However, both our definitions and our common conceptions of what constitutes glare have not been definite or well defined. The work of this committee the past year has, therefore, been confined mainly to the analysis of glare into its fundamental causes and the formulation of precise definitions and data relating to glare. In addition to this general report on the subject of glare the committee has prepared supplementary reports which have been issued from time to time during the past year as follows:

1. General report on glare (classification and definitions).
2. Diffusing media I (classes and definitions of diffusion).
3. Diffusing media II (measurement and theory of diffusion).
4. Papers and inks.
5. Photographic papers.
6. Window envelopes.
7. Interior furnishings.
8. Projection and focusing screens.
9. Diffusing glassware.
10. Effect of glare on vision.
11. Automobile headlights.
12. Interior illumination.
13. Street illumination.

Reports 1 to 9 were drawn up by the chairman of the committee, No. 10 by Richtmyer, No. 11 by the chairman, No. 12 by Cravath, and No. 13 by Vaughn.

* Report No. 1. of the I. E. S. Committee on Glare.

CLASSIFICATION.

Conditions for Comfortable Vision.—The brightness of white diffusing paper in the open on a clear day at noon is about three candles per square centimeter or ten lamberts in full sun *and* skylight, or about three lamberts if illuminated by sky alone. This is about the upper limit of comfortable, accommodated vision. The lower limit is about a millionth part of this or 3×10^{-6} lambert, about the brightness of white paper illuminated by full moonlight. The absolute limit of vision (white threshold) is about 6×10^{-10} lambert.

Now, the illumination of full sunlight would be an intolerable glare under either of two conditions: (*a*) sudden exposure of an eye accommodated to a much lower mean brightness or (*b*) a steady exposure with surroundings very much less bright. The first case is simply a lack of accommodation due to lack of time for adjustment, the second is a similar lack of accommodation due to the impossibility of accommodating to a bright spot and a dark field at the same time. These illustrations indicate the relation of glare to vision. Physiologically, glare, in its broader interpretation, is the direct cause of strained brightness accommodation. There are four classes of strained brightness accommodation:

1. Brightness above the maximum limit of full accommodation. Full noon sun on snow, sand or water are examples of excessive *brightness glare*. Whatever the nature of the adaptation of the retina to the brightness of the image upon it (rate of catabolism of visual purple?) there is an upper limit to it. Brighter images cause distress and excessively bright images, long continued, result in a temporary loss of dark adaptation (snow blindness) lasting for from a few hours to a week. The sole remedy for conditions causing brightness glare is the wearing of absorbing glasses, those transmitting 1/10 of the light (*i. e.*, of density unity) are sufficiently absorbing for snow fields. The solar disk may be viewed comfortably through a screen whose transmission is one millionth.

2. Brightness greatly in excess of that to which the eye is temporarily accommodated produces painful glare lasting nearly until the retinal accommodation has reached the new level. Coming

out of a dark room into full daylight is a familiar example of *temporary glare*. A single short exposure, such as is caused by lightning at night, cause *flash glare*. A succession of flashes constitutes *flicker*. All kinds of glare of this class may be attributed to the lag of accommodation behind exposure. This lag is a real visual economy, since we are constantly viewing objects of different brightness and if there were no lag (amounting to from half a second to several minutes) the wear and tear on the accommodation would necessarily be considerably increased.

3. Brightness localized in a field of much lower or much higher luminosity. This is the case of *contrast glare* or spot glare. The retina tends to accommodate itself to that part of the image falling upon the fovea, in other words upon that part of the field of view upon which the attention is centered. We have no data at present on the distribution of the accommodation over the retina in the case of excessive contrast within the field of vision nor on how this varies with the (*a*) average luminosity of the field (*b*) the size of the brighter areas or (*c*) the location of the brighter areas with respect to the center of attention.

Details are discerned by means of differences in brightness and color. Vision is at its best when contrasts are about 1 : 20, while it is accomplished with effort at contrasts as low as 98 : 100 provided the general illumination be sufficient, and without sensible discomfort if contrasts be less than 1 : 100. Contrasts as high as 1 : 10,000 are not rare, in window frames against open sky, illuminants against their backgrounds or in spots of specular reflection or transmission; these constitute contrast glare.

The physiological basis of contrast glare, is, no doubt, some sort of conflicting tendency among the sets of nerves controlling retinal adaptation. The means of control of the different parts of the retina are only partly independent, hence the general level of adaptation represents a compromise between local tendencies in different parts of the retina. With but moderate contrasts in the field, there is no effort toward local adaptation. It is only excessive contrasts which tend to cause the differential accommodation resulting in discomfort.

In general, no protective glasses can afford any relief from contrast glare. The sole remedy is to reduce the contrasts caus-

ing it by keeping excessively bright spots out of the field of view or by properly using diffusing media of suitable quality. It is only in cases of contrasting fields differing in hue that protective glasses are of any avail. These should be of the dominant hue of the darker part of the field.

4. Brightness below the minimum limit of accommodation causes a strain of whatever controls the accommodation, provided the object viewed be given concentrated attention. Reading dimly illuminated matter is a familiam example. This is not glare proper but a cause producing a related effect.

Our special report on the Effect of Glare on Vision (Report No. 10) deals at considerable length with the various effects outlined above and includes the quantitative data at present available.

Some cases of glare intermediate between classes 1 and 4 require special consideration, cases in which a bright field is composed of numerous fine bright points, *granular glare* for short. Familiar illustrations are sunlight on rough water, frosted glass, sand or rain drops, a starry sky and the like. The resolving power of the eye is about half a minute of arc, that is, the image of any object however small will have a diameter of at least 0.002 mm. on the retina. The image of a distant arc lamp, star or glare spot is spread over this minimum diameter on the retina, hence will appear of lower intrinsic brilliancy and contrast than it really is. In certain cases this effect of angular size of detail is of considerable importance.

Another class of glare producing retinal strain is that in which the object of attention is overlaid with a veil either darker or lighter than the object in which details are to be discerned. Projection on a screen in a lighted room, reflection from varnished wood or glossy paper, a landscape viewed through a haze or a dirty window upon which the sun is shining are illustrations of a bright veil; a landscape viewed through a wire screen not illuminated is an example of a dark veil.

Such cases are called *veiling glare*. Only specular reflection from a glossy surface causes actual brightness glare of the nature of veiling but all cases of veiling cause interference with vision. The resulting discomfort depends in large measure upon the degree of attention given the object viewed.

The pupillary diameter varies from 2 mm. to 7 or 8 mm.; that is, the area of the pupil varies in the ratio of about 1 to 15 in extreme range. The extreme range of retinal sensibility is of the order of ten million to one, so that in the total brightness accommodation of the eye, pupillary expansion and contraction play but a minor part. It is very desirable to know the size of pupil and retinal sensibility corresponding to each brightness of field of vision and a sub-committee is at present engaged in obtaining this data. The only data at present available is that of Nagel (see Helmholtz, *phys. Optik,* II, 264) and others on the increase of dark adaptation with time. Five observers obtain data in substantial agreement. Starting with ordinary daylight interior accommodation, the minimum perceptible brightness corresponds to the flux density given by one meter candle. The reciprocal of this minimum increases with time in the dark about as follows:

Minutes adaptation	0.5	4	9	04	19	31	61	(960)
Threshold sensibility ...	20	75	1,850	10,400	26,000	174,000	215,000	270,000

This may be represented by the equation

$$\log I/I_0 = 6.43\ (1 - e^{-0.101t})$$

t being the time of dark adaptation.

The effect of glare on vision is the basis upon which it is classified and defined. The fact must be strongly emphasized that it depends not upon the objective brightness of the field viewed but upon the subjective brightness sensation. The eye observes brightness and variation in brightness but the scale reading (sensation) is not proportional to the stimulus (light flux) over the whole range of the instrument. It is impossible to measure directly the brightness sensation corresponding to each brightness observed but relative values may be determined by an indirect method.

The sensibility of an instrument is the derivative of its scale reading with respect to the stimulus. Now, the photometric sensibility curve of the average normal eye may be (Nutting, "Applied Optics," p. 127) well represented by the function $P = Pm + (1 - Pm)\ (B/B_0)^n$, B being the (meter-candle) brightness and B_0 the threshold value, and Pm the minimum perceptible photometric difference, about 0.017. The general integral of this or

$$S = C \log [1 + (1 - Pm)(B/B_0)^n - 1]^{1/n}$$

gives the general relation between brightness sensation S and objective brightness B. Over a wide range of moderate brightnesses this reduces to Fechner's law, $S = K \log (B/B_0)$. These relations must be used in dealing with contrast when the field of lower brightness is below that corresponding to a meter-candle on a white reflecting surface.

DEFINITIONS.

Glare.—Glare is brightness within the field of view of such a character as to cause discomfort, annoyance or interference with vision. As pointed out above, glare causes other subjective visual effects and impaired vision may be due to causes other than glare. However, it does not appear feasible to broaden the definition without making it include all forms of improper or defective illumination.

Brightness Glare.—Brightness glare is glare due to an excessive general brightness of the field of view. A brightness approaching or exceeding that of white paper in direct sunlight is considered excessive. The upper limit of comfort for fully accommodated eyes is about 3 lamberts or 1 candle per square centimeter. This limit is illy defined but of nearly the same value for all normal eyes so far as known. If any quantitative expression is to be chosen for brightness glare probably the most rational would be

$$G_b = \log (B/B_0)$$

in which B is the brightness causing the glare to be specified and B_0 is the upper limit of comfort. Thus, a brightness glare of 1 corresponds to a brightness of 30 lamberts, a glare of 2 to 300 lamberts, and so on.

Contrast Glare.—Contrast glare is glare due to excessive contrasts within the field of view. A proper measure of contrast glare is relative total brightness. This holds for the moderate working brightnesses. Relative total brightness is, for nearly normal illumination,

$$\frac{B}{B'} = \frac{Bd + B_s}{B'd + B_s} = \frac{\omega Rd + \pi R_s}{\omega R'd + \pi R'_s}$$

in terms of specular and diffuse brightness B_s and B_d, specular and diffused reflecting power R_s and R_d and solid angle ω subtended by the source.

A quantitative expression for contrast glare applicable at all brightnesses from the threshold of vision up to the highest that are utilized is an expression for the difference in the brightness sensations

$$G_c = \frac{1}{n}\left(\log \frac{1 + Pm\,(B_1^n/B_0^n - 1)}{1 + Pm\,(B_2^n/B_0^n - 1)} - 2\right)$$

Pm being the least perceptible photometric difference (about 0.017), B_1 and B_2 the brightnesses (objective) of the contrasting areas, B_0 the threshold brightness and n a constant equal to about 0.35. The constant 2 signifies that glare begins at contrasts of 100 : 1. This expression is to be used with care since contrast glare varies to some extent with the length of the boundary along which contrast occurs, with the part of the retina upon which the brightest part of the image falls, the degree of general accommodation and other factors.

Veiling Glare.—Veiling glare is that cause of impaired vision due to a light or dark veil obscuring the field of view and of a pattern different from that of the object viewed. The veiling due to a bright veil is greater, the greater the (sensation) brightness of the veil relative to that of the field to be viewed. If the veil is a network or a uniformly illuminated area, probably a mean brightness would serve as a measure of veiling. A quantitative expression for bright veiling glare that would serve is a statement of its effect in reducing contrast. Suppose a veil of brightness V overlies a contrast measured by B/B^1. Then

$$G_v = \log \frac{B}{B'} - \log \frac{B + V}{B' + V}$$

For example, if on a glossy printed page, the contrast between paper and ink is 20 : 1 away from the specular angle and 1 : 1 at the specular angle, then the veiling glare in the latter case is log 20 or 1.3.

Dark veiling is difficult to describe in terms of brightness. It involves a sacrifice of both brightness and definition. The latter effect is so considerable in proportion to the first that a quantitative definition based on brightness alone is of little service.

Temporary Glare and Flicker.—Temporary glare is glare caused by temporary lack of brightness accommodation of the retina. Temporary glare is greater the greater the brightness of the newly

exposed field relative to that of the field to which the retina is accommodated. Now, the only known means of estimating the level of brightness accommodation (see below) is by the magnitude of the threshold. If, now, glare is to be estimated by the ratio of the new brightness to which the eye is tending to accommodate itself to the brightness to which it is already accommodated the temporary glare is properly measured by

$$G_t = \log \frac{B_2}{B_1} - 2$$

where B_1 and B_2 are the two thresholds in question and the constant signifies that glare begins at a ratio of brightnesses of 100:1. This expression is similar to that for contrast glare (see above) but simplified.

Flicker involves not only the ratio of two brightnesses but the rate of accommodation. The brightness sensation, at ordinary brightnesses, rises to half its value in about $^1/_{20}$ second, flicker appears most pronounced at 8 or 10 cycles per second, that is with the transition from dark to light occupying about $^1/_{20}$ second. At low mean brightnesses the rate of accommodation is very much slower. Fluctuations in brightness as slow as 1 per second are very disagreeable. Experiment shows that flicker disappears at a frequency proportional to the logarithm of the brightness. No simple expression more than approximately expresses the relation of flicker sensation to frequency and brightness.

GLARE IN PRACTISE.

Since the photometric sensibility of the retina and, therefore, the sensation of brightness, varies enormously with the brightness of the field of view, any criterion for glare is incomplete unless the temporary retinal sensibility be specified. The fact that this sensibility varies continuously increases the difficulty of specifying it.

The only practical way out of the difficulty appears to be to (1) specify sensibility in terms of the mean level of brightness to which the eye is accommodated and (2) choose and name a limited number of those levels of brightness corresponding to practical working conditions. We, therefore, consider practical lighting problems in glare from the standpoint of the four following different levels of accommodation:

1. Bright daylight in the open. The brightness of the field of view, excluding such extremes as deep shadows and specular reflections of the sun, ranges from nearly white objects in the sun (2 to 10 lamberts) and the open sky (1 lambert) down to foliage (½ lambert) and moderate shade ($^1/_{10}$ lambert). Probably 1 lambert is a fair average for the brightness to which the eye is accommodated under this condition of illumination.

2. Interiors in full daylight. Again excluding such excessively bright objects as those in direct sunlight and such dark objects as deep shadows, the brightness of the field of view in interiors on a bright day varies from the sky at 1 lambert, white paper (0.1 to 0.04 lambert) and walls with a brightness of about 10 millilamberts, down to rugs, dark objects and moderate shadows 1 to 10 millilamberts in brightness. In this case 10 millilamberts is a fair average level of brightness.

3. Interiors artificially illuminated. Unshielded illuminants range in brightness about as follows: arcs from 10,000 to 200,000 lamberts, gas-filled tungsten lamp filaments 5,000 to 8,000 lamberts, ordinary tungsten 200 to 500 lamberts, carbon filaments 150 to 300 lamberts, gas mantles 50 to 200 lamberts, acetylene flames 50 to 200 lamberts, gas flames 5 to 40 lamberts, kerosene oil flames 5 to 100 lamberts. Frosted lamp bulbs range from 1 to 50 lamberts in brightness while diffusing globes and bowls vary from 0.1 to 1 lambert. Such illuminants are supposed to be outside the range of vision except at rare intervals. Objects within the field of view vary from 10 millilamberts down to 0.01 millilambert and lower. A brightness of 0.1 millilambert is about an average for the field of vision in interiors at night. If the illuminants are not properly placed so that one or more of them is continuously or frequently within the field of view, of course the mean eye adaptation is such as corresponds to a higher mean brightness than 0.1 millilamberts.

4. Night Street Illumination. The range of brightness within the field of view out of doors at night is enormous. Excluding artificial light sources viewed directly (see preceding paragraph) the various brightnesses ordinarily within the field of view are roughly: white objects in full moonlight 0.01 millilambert, foliage, roads and pavements in full moonlight 0.0005 millilambert.

The same objects under starlight are about $^1/_{20}$ as bright. Objects can be just descerned with full accommodation at about 10^{-6} millilamberts. Considering only brightnesses necessary and comfortable to the eye, probably 0.001 millilamberts represents a fair average for night vision in the open.

The four levels of brightness determining the four chief levels of accommodation may be thus summarized.

	Average brightness level	Preceptible percentage difference	Relative retinal sensibility
1. Exterior daylight..........	1000 ml.	0.0176	1
2. Interiors in daylight	10	0.030	59
3. Interiors at night...........	0.1	0.123	1430
4. Exterior at night	0.001	0.79	22300

The percentage perceptible difference is the difference in brightness that is just perceptible (from data of A. König) expressed as a fraction of the whole. Retinal sensibility in the last column is proportional to the increment just perceptible calculated from the data of König. Such data are to be regarded as tentative only. Your committee is now engaged in its direct determination.

Such data give a basis for the quantitative estimation of glare under various conditions. For example, assuming the above data correct, an area so bright as to be blinding in broad daylight must be about 60 times as bright as one that is blinding in an interior in the daytime and 22,000 times as bright as a surface blinding at night out of doors. The light sufficient to read by, to just distinquish objects by and the brightnesses causing fatigue or strain are known to vary in somewhat similar proportions at the different levels, but exact data are not yet available.

At each level of accommodation a number of brightness sensations may be defined (such as dazzling, blinding, excessive, uncomfortable, annoying, normal, defective, deficient, signal and threshold) in terms of the brightness causing them relative to the mean level. It may be desirable ultimately to define quantitatively a set of such terms but only after the relation of each to brightness and angular area shall have been investigated.

An important relation that has been noted by several writers should be emphasized here, namely that the more contrasty the field of view the higher the level of illumination demanded by the eye for acute, comfortable vision. In machine shops where large

dark areas are general and specular glare common, much more light is required for good seeing than in say a living room with no specular surface, indirect lighting and light walls and floors. Your committee are not prepared to state the relation between proper average brightness and mean contrast but do not doubt that such a relation exists and that it may be determined and formulated. Data are now being obtained by a sub-committee.

The special reports prepared by this committee are listed below. Report No. 6 was prepared at the request of the National Letter Carriers Association, No. 11 at the request of the Automobile Association. The remaining reports were prepared solely in the interests of illuminating engineering:

REPORTS OF COMMITTEE ON GLARE.

1. *General Report on Glare.*—Nature of various classes of glare, the effect of each on vision, limits of tolerance and means of suppression.
2. *Diffusing Media I.*—Classes of diffusion, nomenclature and physical theory of diffusion.
3. *Diffusing Media II.*—Instruments and methods for measuring diffusion and theory of diffusion photometry.
4. *Papers.*—Print papers, sizings, fillers, inks. Writing papers and inks. Typewriting papers, inks and carbons. Drawing papers and India inks. Tracing papers and cloths. Blue print papers. Photostat papers.
5. *Photographic Papers and Plates.*—Glossy, semi-glossy, semi-mat, velvet, rough and mat papers. Stocks, finished papers and developed papers in three densities. Raw plates, negatives.
6. *Window Envelopes.*—Diffusion analyses of various kinds in use.
7. *Furnishings.*—Walls, ceilings, floors, woodwork, fixtures, shades, draperies and furniture; unfinished, finished, and covered. Brightness, contrast and veiling glare.
8. *Projection and Focusing Screens.*—Washes, cloths, metal and special coverings. Focusing and translucent projection screens.
9. *Diffusing Glassware.*—Ground, frosted, etched and flashed globes and shades.

10. *Effects of Glare on Vision.*—Excessive and deficient illumination, temporary glare, excessive contrast, veiling, fatigue, annoyance, discomfort, loss of brightness adaptation, loss of acuity, permanent injury.
11. *Automobile Headlights.*—Causes of excessive glare, minimum requirements in lighting and warning. Headlight regulation.
12. *Interior Illuminants.*—Intensity, character and position of lighting units.
13. *Street Lighting.*—Character, brightness and spacing of lighting units.

The character of each report is indicated by the brief outline of each. Reports 2-9 inclusive deal with diffusing media, No. 10 with visual effects and 11, 12 and 13 with practical engineering problems. In Report No. 2 are defined various terms used in dealing with scattered light such as reflecting power, transmission, opacity, turbidity, entrant scatter, exit scatter, optical density and specific density, contrast and gloss. In the report on papers are given the results of complete diffusion analyses of many kinds of papers, inks, fillers, sizing, etc. Of particular interest are gloss, specific density, back reflection and contrast ratio. Photographic papers are produced with a wide variety of accurately reproducible surfaces such as rough, textile, mat, semi-mat, semi-glossy and glossy, each having, in the finished print, a wide range of diffuse reflecting powers. It is on account of the interest attached to the study of such surfaces that this report is included in the series.

Window envelopes are desired as transparent and as free from diffusion as possible, properties quite the opposite of those required of print papers. The ease with which print may be read through the prepared window is quantitatively defined in contrast ratio. The specular and diffuse reflecting power of interior furnishings, upon which home and office comfort so largely depend are discussed in report No. 7. In the report on projection screens (No. 8) are given accurate diffusion analyses of various types of screens. Screen efficiency is defined and the properties of an ideal screen and of the best realizable screen given. Diffusing glassware is treated from both the laboratory and engineering

points of view. Report No. 10, on the effects of glare on vision, is one of the most important of the series since its effect on the eye is the ultimate criterion not only of glare but of good and bad lighting. Report No. 12 deals with various engineering problems in interior illumination and No. 13 deals in a similar manner with street illumination.

A complete bibliography of glare and related effects would be very extended; nearly all the literature of glare is readily available in the TRANSACTIONS of our society. To those desiring to read further on the subject we recommend the various reports of the committees on glare, the papers by Dr. Cobb on the effect of glare on visual acuity, of Professor Ferree on the effect of excessive and deficient illumination, Mr. Luckiesh on glare in its various aspects, Mr. Cravath on brightness, Mr. Minick on headlights and Mr. Sweet on street illumination.

Your present committee has felt that the work most urgent for them to do lay in the field between the optical laboratory and illuminating engineering and extending into both. We have endeavored to secure the data and formulate the relations most needed by the illuminating engineering profession in improving illumination and lighting practise, leaving to later committees the work of expanding and popularizing this material.

Your committee consider that the line of progress in glare research lies in the further investigation of adaptation levels of the retina, of local and partial adaptation and of limits of tolerance in proper lighting. Another line of work urgently demanding attention is required to fill the gap between laboratory and practical engineering data.

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THE EFFECT OF GLARE ON VISION.*

Synopsis: What is known of the visual effect of radiation is outlined. Retinal phenomena, retinal adaptation to flux density, optic images, pupillary adaptation and deleterious effects of radiation are discussed. The following subjects are also discussed briefly: glare and vision; effects of excessive brightness, momentary and continuous; conjunctivitis; keratitis; retinitis; effects of excessive contrast; discomfort, interference with vision; effects of excessive extra visual radiation; and effects of veiling glare and flicker.

INTRODUCTION.

In many respects the viewpoint from which this report of the effect of glare on vision is written must necessarily differ materially from that of other reports in this series. Many, if not all of these reports deal to a greater or less extent with definite quantitative data, on the basis of which precise statements of facts are possible. With visual phenomena, however, particularly in connection with the deleterious effects of glare, little data, qualitative or quantitative, is to be found, and what there is seems more or less conflicting. To a large extent, therefore, this report is to be regarded as the committee's *opinion* as to the nature of the effects of glare on vision, as based on evidence now available. On account of the necessity for brevity, detailed references have been omitted.

Since any discussion of the physiology of glare must be very closely connected with the more general question of the deleterious effects of radiation on vision, a few introductory statements seem necessary regarding radiant energy, the eye, and the physiology of vision.

The general nature of the propagation of energy by wave motion is assumed to need no discussion here. Excluding X-ray radiation the shortest waves yet observed have a wave-length of 0.000006 cm. From this point, the known wave-length extend in an unbroken sequence up to the longest electromagnetic waves, the length of which is measured in miles. This series is frequently thought of as divided into four parts: (1) the ultra-violet, extending from the shortest known waves (excluding

* Report No. 10., I. E. S., Committee on Glare, 1914-15.

X-rays) up to the point where ordinary vision begins, somewhere in the neighborhood of 0.00004 cm.; (2) the visible, extending for one octave from about 0.00004 cm. up to the upper limit of vision, approximately 0.00008 cm.; (3) the infra-red, extending from here up to waves a few tenths of a millimeter; (4) beyond this point begins the region usually thought of as comprising the electromagnetic waves.

Similarly, the known effects of radiation can be divided into four classes. (1) The heat effect; (2) the chemical effect; (3) electric and electromagnetic effects; (4) the visual effect.

The division of the spectrum into four parts is obviously quite artificial. It is based solely on the circumstance that the visual effect comprises the octave between 0.00004 and 0.00008 cm. The same may be said regarding the classification of the effects of radiation. It might be safe to predict that when our knowledge of physical processes is sufficiently extended we shall explain all phenomena on the basis of the electromagnetic effect.

The heat effect of radiation throughout the spectrum is proportional to the energy at each wave-length. Since in the spectra of modern illuminants the energy is greatest in the infra-red, the infra-red waves have sometimes been called heat waves. This classification is evidently erroneous. In this sense *all waves* are heat waves.

The chemical effect of any part of the spectrum is a function of both the energy contained in, and the wave-length of, that part. In other words, the chemical effect is selective. No definite statement of its extent can be made. In general the shorter visible rays and the longer ultra-violet rays are the more active chemically. But it is quite incorrect to speak of violet and ultra-violet radiation as chemical radiation. Photochemical effects are known well into the infra-red.

Regarding the electromagnetic effect, little need be said in this connection. Since radiant energy is itself electromagnetic, its effects must be ultimately expressed in those terms.

THE VISUAL EFFECT OF RADIATION.

As to the ultimate nature of the visual effect, with which we are directly concerned in this report, it would obviously be evading the question to say that it is electromagnetic. For while such

a statement is probably true, broadly speaking, we cannot explain the transformation of radiant energy into visual sensation by means of what are now recognized as electromagnetic phenomena.

There are no reasons for assuming that the visual effect of radiation is *simply* a heat effect. The latter, as explained above, is common to all parts of the spectrum, while the former is highly selective. Further, granted that there might be in the retina a selectively absorbing medium capable of making possible, by temperature changes, the selective character of vision, it is difficult to conceive of the myriad of visual sensations being produced by thermal phenomena. It is, of course, true that a visual sensation results from electric currents in the optic nerve fibers, and it is further known that light, falling on the retina, produces electric effects in the optic nerve. It is thinkable that the rods and cones of the retina are sensitive thermo-electric receivers. Our knowledge of thermo-electric phenomena, however, does not point to it as a suitable basis for a working theory of vision.

There remains, as a basis for an explanation of visual processes, the chemical effect. About all that one is warranted in saying at the present time is that an explanation on this basis is a possibility. Several hypotheses have been advanced but all are but little more than speculation.

Since so little is known of the fundamental processes by means of which radiant energy is transformed into visual sensation, it is evident that any discussion of the peculiarities of these processes must be either empirical or superficial.

RETINAL PHENOMENA.

The reception of radiant energy on the retina is known to produce at least three results in the retinal media:

(1) A change in shape of the cones. The tips of the cones recede when illuminated, due to the body of the cone becoming shorter and thicker. (2) Closely connected with (1) is the so-called "migration" of the dark pigment. On exposure to light the pigment bearing cells push up towards the tips of the rods and cones. Conversely, they recede toward the base of the cones in darkness. This pigment migration has been found in some lower animals but has never been observed directly in mammals. (3) Most significant of all, the visual purple, a watery fluid purp-

lish in color, is bleached to yellow or even "white" on exposure to light. Different wave-lengths have different bleaching powers. A curve showing the bleaching power of various parts of the spectrum is quite similar in shape and position to the luminosity curve. The chemical or physical changes corresponding to the bleaching of the visual purple are not known. Nor is anything definitely known regarding the relation of this phenomena to visual sensation. Several hypotheses have been advanced but all have obvious difficulties.

Among the retinal phenomena which may be observed subjectively and which have an important bearing on the subject of glare may be mentioned two:

(1) *Retinal adaptation,* frequently called light or dark adaptation, is a phenomenon well known, qualitatively at least, to everyone who has experienced the sensation of not being able to see when first entering a darkened room from full daylight; or, the reverse, the pain experienced when first going from a darkened room into full sunlight. Quantitatively, retinal sensibility is defined as the reciprocal of the minimum observable (threshold) illumination. In terms of the meter-candle on a white surface, the retinal sensibility is nearly unity for the eye adapted to sunlight. On entering a dark room, adaptation is rapid at first, then slower and slower. It continues until at the end of an hour it has reached a value of about 200,000. That is, after an hour's rest in the dark the minimum observable illumination is 1/200,000 of what it is with the eyes accommodated to sunlight.

The return from a condition of dark adaptation to light adaptation is much more rapid, being accomplished in a few seconds.

One important result of the phenomena of adaptation is that, under different condition, the *same* sensation may be caused by widely different brightnesses. Thus, with the eye adapted to sunlight, the threshold sensation is just caused by 1 meter candle on a white surface. But with the eye adapted for one hour, the same sensation can be caused by 1/200,000 of a meter-candle. One might conclude therefore, that with the sunlight adapted eye an illumination of 100 meter-candles would cause the same sensation as 1/2,000 of a meter-candle with the eye dark adapted. This does not necessarily follow. For with the eye exposed to

1/2,000 of a meter-candle, it is no longer in a condition of adaptation where 1/200,000 meter-candle excites the threshold sensation, on account of the rapid change from dark toward light adaptation noted above.

Whatever may be the nature of the processes by which radiant energy is transformed into visual sensation, or by which adaptation may be accomplished, it seems reasonable to assume that there is at least a rough correspondence between sensation and the physiological activity which causes it. In other words, the *intensity of physiological reactions produced by the reception of radiant energy on the retina depends both on the flux density of that radiation at the retina and on the state of adaptation of the eye.*

(2) Brief mention should be made of the formation of after-images in the eye. Two kinds of after-images are recognized.

(*a*) *Positive After-Images.*—If the eyes be kept in the dark for a few minutes, and then suddenly exposed for two or three seconds, a "positive" image of the field viewed will be seen. This will gradually fade. The intensity of the after-image caused by a given brightness depends on the condition of adaptation of the eye. With the eye fully dark adapted one may observe the positive after-image of a window looking out on a moon-lighted scene. With the light adapted eye far higher intensities, those usually met in daylight, are necessary to produce after-images.

(*b*) *Negative After-Images.*—These may be observed by gazing steadily for two or three minutes at a field in which there is excessive contrast. On looking at a white wall a "negative" after-image is observed. With negative after-images thus observed, not only are light and shade reversed, but colors are usually seen complementary. Negative after-images frequently follow a faded positive after-image.

The following two statements may be made, based on the phenomena of after-images: (1) The physiological processes set going by the reception of radiation on the retina persist for some time after the radiation is cut off. (Positive after image.) (2) The ability of any part of the retina to respond to a given stimulus depended on its immediate previous history; thus, where one

observes the negative after-image on the white walls those parts of the retina previously stimulated in excess of their surroundings are not able to produce from the same stimulus as great a sensation as their surrounding parts.

Pupillary adaptation, as a result of varying brightness, is well known. Under normal conditions, the size of the pupil may vary from something less than 2 millimeters to something over 7 millimeters, causing by "stopping down" the optical system of the eye a variation in brightness of the physical image found on the retina of from 1 to 20. Pupillary adaptation is a function of the actual brightness of the field viewed, of the state of retinal adaptation, and perhaps also of the color of the active light. It is "a reflex act, secondary to retinal stimulation."

MEANS AVAILABLE FOR STUDYING EFFECTS OF RADIATION.

The above are some of the ocular phenomena incidental to vision. If one excludes such unusual cases as snow blindness, ultra-violet "burns," etc., which are seldom if ever experienced by the average individual, we know of no structural change in eye media coincident with any of the deleterious effects of radiation on vision. These disturbances produced are largely functional, and they must, therefore, be studied by such phenomena, observable objectively or subjectively, as are known to be closely connected with the processes which result in visual sensation.

For example, a study of retinal adaptation gives much information regarding the pathological condition of the retina. The following clinical observations are illustrative:

Several patients (*Arch. f. Ophth.,* vol. 82, p. 509) complained of flickering sensation, inability to see clearly for a long time after coming into a light room from a dark room, and other general disturbances to vision, due, apparently, to working under improper artificial illumination. A test of the time adaptation curves showed threshold sensibilities far below normal, indicating a serious functional disturbance—whatever its nature—in the retina.

Likewise, observation by means of after-images, pupillary reactions, examination of the light and color limits of the periphery

of the retina are some of the phenomena by which the oculist can study functional disturbances in the eye.

GLARE AND VISION.

Below will be briefly summarized some of the effects of the various recognized types of glare on vision. For purposes of this report, we will keep in mind the effect of each of the several types of glare as follows: (*a*) Effect on external and internal eye media, (*b*) effect on muscular apparatus of the eye, (*c*) functional disturbances produced in the retina. The last is by far the most important.

EXCESSIVE BRIGHTNESS.

Glare due to excessive brightness may be of two kinds: (1) momentary, (2) continuous.

When the more or less completely dark adapted eye is suddenly exposed to a higher illumination, the eye is "caught unawares" with the pupil wide open and with the retina in a condition to register weak light intensities. Excessive retinal stimulation results. This causes a "blinding sensation," as a result of which there is a sudden contraction of the pupil so intense as to be painful. There seems also to be some reason to believe that the intense stimulation of the retina causes pain. Very quickly the retina adapts itself to the new intensity—or at least attempts to do so. If the brightness is not too intense, a condition of comparative comfort is soon reached. The glare is then said to have been *momentary*. In probably the vast majority of cases there has been no injury, even temporary, except when the process be repeated rapidly, many times in succession, or when the eye is exposed to an excessively brilliant momentary flash.

In some cases, however, the brightness may be so intense that the sensation of discomfort or pain does not disappear after a few seconds but persists. The glare is then said to be *continuous*. Such conditions obtain when the eye is exposed to the excessive brightness from large snow fields, deserts, the flash of an electric switch, etc.

The reduction of the physiological activity by both pupillary and retinal adaptation is not in case of continuous glare sufficient to reduce the stimulus to an allowable maximum. There results pain due in part to the continued attempt of the iris to close

further; excessive bleaching, without possibility of restoration of the visual purple, and a general condition of muscular strain resulting from squinting and tension of external eye muscles.

The effects appear to be much more harmful if the excessive brightness is located beneath the general eye level. (This might be anticipated by a consideration of the conditions under which primitive man was developed.)

In cases of continuous glare due to excessive brightness of long duration, there results such ocular disturbances as snow blindness, desert blindness, etc., which, in addition to being accompanied by external irritating, result in a temporary or semi-permanent loss of power to dark adapt.

Among the classified disorders recognized by oculists as arising from long continued exposures to excessive brightness may be mentioned:

1. *Conjunctivitis.*—An inflammation of the conjunctiva, the membrane covering the inner surface of the eyelids and the outer surface of the eyeball. The eyes become blood-shot; there are sensations of sandiness; sharp, shooting pains; heaviness of the eyelids; and marked dryness. Unless the exposure be of too long duration, "recovery usually follows the removal of the cause."

2. *Keratitis.*—Inflammation of the cornea, accompanied by cloudiness and consequent impairment of vision.

3. *Retinitis.*—Inflammation of the retina, with accompanying functional disturbances.

Sun blindness (solar retinitis) has resulted in a number of cases from direct observation of the sun. There is partial (or absolute?) blindness of the central portion of the retina, defective color vision, reduction of visual acuity, and an apparent distortion of objects in the field of view. Frequently, ophthalmoscopic examination of the retina shows no change, or there may be a small orange spot near the fovea, with alterations in pigmentation. It is stated that in no case in which vision was reduced to less than one third has there been full recovery of visual acuity.

Snow blindness may be so serious as to result in permanent blindness. There are the ordinary symptoms of conjunctival and corneal inflammation, spasmodic contraction of the eyelids, frequently corneal ulcers, intense deep-seated pain when the eye is

exposed to light (photophobia) quivering and unsteadiness of vision, but no retinal changes observable by means of the ophthalmoscope.

Until we know more about the phenomena of vision we can only speculate on the ultimate nature of the retinal disturbances incidental to the above diseases. For example, continuous excessive brightness causes an excessive bleaching of the visual purple. Now if this acts in an electro-chemical way to produce vision, the physiological processes caused by it are continuously over-stimulated, as are likewise the processes by which the visual purple is renewed. Obviously, as in any bodily function, whatever the nature of the processes underlying vision, the excessive stimulation of any or all of them for a long period must result in a lowering of the efficiency with which they can be carried on. In other words, the deleterious effects of excessive brightness seem to be primarily due to continued over-stimulation of the retinal processes by visible radiation rather than to the presence of extra-visual radiation.

The obvious remedy for glare due to excessive brightness is the use of neutral tinted glasses of suitable density.

EXCESSIVE CONTRAST.

Glare due to excessive contrasts occurs when the general level of the brightness of the visual field is not above the upper limit for which the eye can readily adapt, while within the field there exists more or less restricted areas whose brightness is much above this level.

The brightness of these areas may be (1) so great as to cause of themselves, injury by over-stimulation of restricted areas (as in the case of bare light sources) or (2) they may be such as to cause simply a reduction of visual acuity and the ability to distinguish contrasts in surrounding parts of the visual field, causing simply "annoyance, or interference with vision." (1) depends in large part, perhaps entirely, on the absolute brightness of the area concerned; (for upper limit of brightness permissible within the visual field see other reports in this series); on the retinal area on which the image falls; and, perhaps, to a small extent on the condition of adaptation of the eye. (2) depends quite as much on the condition of adaptation of the eye as on the absolute

brightness of the objects concerned. "Interference with vision" due to (2) is from three causes:

(*a*) It is well known that an excessively bright area, even though small as compared with the whole field, will cause a contraction of the pupil, thereby reducing the physical brightness of the image of the whole field as formed on the retina. Certain experiments seem to indicate, however, that this effect is in part compensated for by increased visual acuity due to having the lens stopped down.

(*b*) The eye media cause a slight scattering of the light from the excessively bright area, causing the equivalent of veiling glare over the areas immediately surrounding the bright source.

(*c*) More important still, the existence of excessively (relatively) bright areas within the field of vision tends to shift retinal adaptation toward that required for the brighter area. Whatever the process of adaptation, it is probable that one part of the retina is affected to some extent by the adaptation of another part. Consequently, or inability to see detail in a dark field in the foreground of which is a bright light source is in part to causes exactly the same as those which make it impossible to see, at first, when entering a darkened room from sunlight. That is, it is simply a matter of adaptation.

The deleterious effects of excessive contrast depend in part on the relative sizes of the contrasting areas. With large contrasting areas (brilliantly lighted table top, with remainder of room dim) re-accommodation both pupillary and retinal is necessary as one shifts one's gaze from the brighter to the darker area and *vice versa*. If this re-accommodation occurs too frequently interference with visual functions may result. On the contrary small "checker-board-like" contrasting areas do not necessitate such re-accommodation, and from that standpoint are less objectionable.

As studied subjectively, we can divide the effects of glare due to excessive contrast into two classes:

(1) Ocular discomfort. This manifests itself by a "sandiness" which "soon passes over into a sharp, stinging pain, followed by a muscular discomfort, an aching in the ball of the eye which, if the exposure is continued long enough seems to radiate to the socket and the surrounding regions of the face and head."

This discomfort is not felt in the retina as a result of over-stimulation, but in the other parts of the eye.

(2) Simple interference with vision, by reduction of visual acuity, etc.

Ocular discomfort depends on the intrinsic brilliancy of the bright area and on its extent. Thus, the ocular discomfort arising from a 500-watt tungsten lamp within the field of view is greatly reduced by surrounding the lamp by a suitable translucent shade. In general, bright areas within the field of view which leave persistent negative after-images, are to be avoided.

Interference with vision, however, seems to depend on the total light entering the eye from the bright area. Thus, while a globe around a 500-watt lamp largely eliminates ocular discomfort, it does not materially reduce interference with vision, unless the intrinsic brightness of the area be brought down to the general level of that in the field of view (under which condition excessive contrast no longer exists). In this connection it has been shown that if the interference with vision be expressed as a "blinding effect," which quantitatively is "the per cent. increased illumination for equal clearness of vision as compared with conditions where the blinding effect is absent," then the so-called blinding effect is proportional to the square root of the candlepower of the bright area (source) in the field of view.

Protective neutral tinted glasses may be of value in eliminating ocular discomfort due to contrast glare. They obviously cannot materially reduce interference with vision, since they simply reduce the general level of brightness and therefore of adaptation, but do not reduce the contrast.

EXCESSIVE EXTRA-VISUAL RADIATION.

In spite of a great deal of experimentation and speculation on the effect of extra-visual radiation on eye media and the visual functions, no very definite conclusions have been reached. There is, for example, much disagreement as to the limits of transparency of the several eye media in the ultra-violet. One observer states as follows:

Cornea: Transparent above 0.295μ; opaque below.

Lens: Increasing transparency from 0.350μ to 0.400μ; completely transparent above 0.400μ.

Vitreous: A $^3/_{16}$-in. layer shows a broad absorption band from 0.250μ to 0.280μ, with a maximum at 0.270.

Another observer states that light wave lengths shorter than 0.320μ cannot pass the cornea. Another states that, with sufficiently intense radiation, lines in the neighborhood of 0.30 are distinctly visible *as lines.*

Less work has been done regarding the transmission in the infra-red region. It is concluded that "the total energy transmitted through the several layers of eye media, as they exist in contact with each other, is about the same as that transmitted through an equal quantity of water."

Ultra-violet radiation may be visible indirectly, by the fluorescence which it produces in the lens (and retina).

Over-exposure to ultra-violet radiation produces a "burn." After a time, perhaps a few minutes, frequently many hours, there results pain in the eyes, a deep-seated itching, sensitivity to light, twitching and swelling of the lids. There is strong contraction of the pupil and conjunctival discharge. Examination shows a contraction of the visual field, reduction in visual acuity and partial or total loss of dark adaptation. Complete recovery requires several days. In the more severe cases there may be permanent reduction in visual acuity. One authority states that the source of the trouble comes from rays shorter than 0.330μ. Others seem inclined to put the limit somewhat lower.

No definite statement can be made regarding the effect of infra-red radiation. In general, however, no deleterious effects comparable to those due to ultra-violet radiation seem to have been observed. Even in the case of radiation comparatively rich in infra-red, it is probable that the absorbing power of the anterior eye media sufficiently protects the sensitive retina from injury, except for the most intense and unusual cases.

It is probable that the harmful effects of extra visual radiations on the retina cannot be expressed completely in terms of the wave length and intensity of the radiation concerned. The condition of the eye is a very important factor. For example, if the eye be dark adapted, just as it is more sensitive to visible radiation, so also it may be more sensitive to the effect of ultra-violet radiation. It is possible that, by reason of being light adapted,

the retina is protected from the ultra-violet of daylight, while with the eye partially dark adapted there is insufficient protection against the smaller amount of ultra-violet contained in artificial illuminants. In other words, the mere fact that artificial illuminants contain proportionally less ultra-violet than daylight is not *of itself* a proof that the ultra-violet of modern light sources is not harmful. The effects of ultra-violet radiation are probably due to atomic disturbances; *i. e.*, are chemical in nature. Since the chemical effect of radiation is selective, the intensity of the disturbances due to this cause are a function not only of the energy contained in the radiation itself, but of the character of the receiver. We may not be able to specify structurally, wherein the dark adapted eye differs from the light adapted eye, but functionally we know that a great difference exists.

It is safe to say, in spite of our lack of knowledge of the nature of the harmful effects of radiation, that where the eye is exposed to radiations known to contain relatively large amounts of extra visible radiation, one should use protective glasses which cut off, so far as possible, the ultra-violet and infra-red. Except for esthetic reasons there is no particular harm in using a glass which cuts off also some of the visible spectrum, if that be necessary to insure complete elimination of the extra visual content.

VEILING GLARE AND FLICKER.

These conditions which cause ocular discomfort are dismissed together, because it is probable that a large part of the source of trouble is not directly physiological but is to a certain extent psychological. The connection between the eyes and the various bodily functions is well known. To a layman, this indicates that a comparatively slight cause may seriously disturb the "equilibrium" existing in our ocular apparatus. Thus, there are twelve muscles which rotate the eye-ball in its socket. Each eye must be so oriented that the image viewed will fall on exactly the same part of each retina—an adjustment which must be made with the highest precision. Evidently, this requires "a most complicated and delicately balanced set of muscles and nervous connections—and a small but persistent disturbing circumstance may work not only great discomfort, but in extreme cases, such confusion of the various eye movements as to make vision well nigh impossible."

When we consider the still more delicate mechanisms which operate the iris and the lens, it is safe to say that any condition which, however little, interferes with comfortable vision must, if continued, result in ill effects. Even were the data available, it would be beyond the scope of the present report to analyze the various conditions coming under the above head.

Veiling glare (see examples mentioned in other reports) results in insufficient contrast. "The seeing is bad." One feels (perhaps unconsciously) an annoyance at not being able to distinguish clearly, and with ease, detail in the field of view. These are possibly efforts to refocus. The annoyance, mental and ocular, causes a strained condition in all parts of the visual apparatus, so that, even though the brightness be within the limits of tolerance, and the radiation reaching the eye contain no specifically harmful component, serious harm of a more or less nervous nature, may result.

The same remarks apply to flicker—either in brightness or in space. The general dissatisfaction at not being able to see clearly is of itself largely the cause of the ocular discomfort. In displacement flicker there is the added strain on the external eye muscles, and in brightness flicker a corresponding strain on the iris due to constant attempts at pupillary adaptation, and if the range of brightness be extreme, there is continual retinal adaptation.

"It is a great though often forgotten physiological law that any organ, exercised within its limits, tends to increase in power, and facility, while if overworked it becomes less and less able to do any work at all. If a man habitually uses his eyes in strong lights he decomposes his visual purple faster than it can be regenerated. If he uses his ciliary muscles without rest, day after day, they begin to break down under the strain and become fatigued even by short periods of use."

Permissible fluctuations in brightness depend on the adaptation of the eye and on the time rate of change of brightness. Thus 10 per cent. "sine-wave" changing in brightness with a period of several seconds would not be so objectionable as an abruptly alternating increase and decrease of brightness of the same period and amount.

When the fluctuations of brightness are sufficiently high so as not to give the sensation of flicker, common experience seems to indicate that there is no harmful effect. It has been shown that the optic nerve can transmit a flickering sensation whose frequencies are far higher than those, (*i. e.*, 40 or 50-light cycles per second) at which vision becomes continuous. This indicates that the damping out of the flicker must occur in the retinal processes, and hence there can be no reflex excitation of the pupil or other ocular apparatus whose functioning depend on light sensation.

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YELLOW LIGHT.*

BY M. LUCKIESH.

Synopsis: A discussion of the importance of color in lighting and vision would be too extensive to be treated in a single paper. However, inasmuch as most artificial illuminants are decidedly yellow as compared with daylight and as yellow light has some distinctly different properties as compared with many other illuminants, a brief discussion of its place in lighting is presented. The knowns and unknowns, and the various opinions regarding yellow light are discussed briefly with respect to visual acuity, glare, fatigue, penetrating power, and esthetic value. The procedure involved in altering the light from tungsten lamps to a match with the light from the kerosene flame and old carbon incandescent lamp is presented together with the resultant efficiencies of the altered light for tungsten lamps operating throughout the extreme present range of luminous efficiencies. The error usually made in attempts to simulate the color of the older illuminants by means of screening tungsten lamps with yellow filters is pointed out, and illustrated by a comparison of the ideal transmission screens for accomplishing this purpose with ordinary amber glass of various densities which is usually used.

The importance of the color of illuminants and their surroundings has become very evident to the lighting expert. In fact color is so influential in lighting and vision that certainly the problems would often be extremely simplified if color-vision ceased to exist. Yet few persons realize that the ability to see color complicates the study of lighting and vision very much. A treatment of the subject of color in its relation to lighting would be far beyond the scope of a brief paper, but inasmuch as the majority of artificial illuminants are yellowish in color, yellow light will be briefly discussed. There are many unsolved problems pertaining even to this narrowed field as will be seen by the confused state of affairs. Any color phenomenon is so complicated that the chief difficulty in interpreting observations lies in the absence of properly recording or weighing all the influential factors found in a given case. Too often matters of taste are construed as general facts. The physical problems are usually easy to solve. The

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physiological and psychological problems are more difficult to study owing to the vagueness of the criteria but these problems are certainly capable of solution. However, the problems which involve merely the esthetic taste are indeterminate. An attempt will be made briefly to point out the knowns and unknowns and to discuss the opinions and conclusions of various observers regarding those phenomena which are of chief interest in a discussion of yellow light.

Visual Acuity.—Some years ago it was shown that monochromatic light was superior to light of an extended spectral character for the perception of very fine detail. An investigation[1] showed that monochromatic light near the middle of the spectrum, namely yellow light, was superior for the perception of fine detail to monochromatic light of any other wave-length. More recently the author[2] has investigated visual acuity in daylight and ordinary tungsten light. This problem has been studied under various conditions in connection with other work with the general result that visual acuity was found to be practically the same under equal intensities of illumination for these two illuminants. These tests were made on fine parallel lines at the threshold of discrimination. In some of the work by the author and others another criterion was used, namely that of equal readability or clearness of a page of type. This latter criterion approaches more nearly to the predominating condition found in practise and has proved to be sufficiently definite to commend its use in practical investigations. For instance in reading, the characters are recognized in groups and the eye is not focused on individual letters but travels across a page in a series of jumps. Even though the eye did examine each letter or portion of a letter the illumination is usually sufficiently high so that the size of the detail is far above the limits of discrimination.

Owing to the fact that yellow paper is often declared to be "easier on the eyes" it was thought of interest to ascertain if there was an appreciable difference in visual acuity when fine lines were viewed against backgrounds of white and yellow copy paper.

[1] Luckiesh, M., The Dependence of Visual Acuity on the Wave-Length of Light; *Elec. World*, 58, p. 1232, 1911.

The Influence of Spectral Character of Light on the Effectiveness of Illumination; TRANS. I. E. S., vol. 7, p. 135, 1912.

[2] Luckiesh, M., Visual Acuity in White Light; *Elec. World*, Dec. 6, 1913.

The illuminant was artificial daylight of approximately the same spectral character as noon sunlight. The reflection coefficients of the white and yellow papers for this illuminant were 0.77 and 0.69 respectively. Under equal illumination visual acuity was found to be practically the same with a slight tendency to be better with the yellow copy paper as a background. When the backgrounds were equally bright visual acuity appeared to be slightly but definitely higher with the background of yellow copy paper. The illumination used varied from 3 to 10 foot-candles. It should be noted that this paper was a pale and unsaturated yellow in color. Although there was no appreciable difference in acuity when the two backgrounds were illuminated to equal flux densities it is apparent that the light reflected from the yellowish paper, in which the blue and violet rays were somewhat suppressed, showed a slight advantage per unit of brightness over that reflected from the white paper in respect to defining power. This does not necessarily indicate that the unsaturated yellow light was better for revealing fine detail than any other unsaturated color, although other evidence points to this conclusion. Further, with a given illuminant such as the light from a tungsten lamp, apparently little advantage is gained in visual acuity by screening out some of the visible rays of short wave-length. If this screening were carried further possibly some advantage might appear. It appears quite likely that, at the higher illuminations where visual acuity decreases slowly with decreasing illumination, the reduction in visual acuity due to decreased illumination, which is the result of the screening process, would be more than overcome by the increasing definition due to the approach toward monochromatism of the light passing through the screen. This point is open to further investigation.

Glare.—The opinions regarding the relation of the color of the illuminant and glare are quite conflicting. This state of affairs is no doubt largely due to the indefiniteness of the criteria and the lack of an approved method of measuring the vague condition known as glare. The opinions that have been expressed on this point are usually associated with headlights. It is strongly asserted by some that a yellowish headlight is less glaring than a white one. While the author does not wish to be understood

as supporting this conclusion it has often appeared to him that a greenish-yellow headlight which was experimented with considerably, appeared to be noticeably less glaring than a 'white' light without the greenish-yellow screen, the units being of equal wattage. The greenish-yellow screen, however, absorbed about 25 per cent. of the total light which was emitted by the tungsten lamp used.

On the other hand others have strongly asserted that yellow, orange and red rays contribute more to the production of glare than the visible rays of shorter wave-lengths. In fact the ideal illuminant according to these observers is one that has even less of the yellow, orange and red rays than daylight. However, until more convincing evidence is submitted this question is unanswered.

Yellow and yellow-green glasses are worn considerably for protecting the eyes from the glare of daylight. That such glasses reduce glare is quite apparent especially when the eyes are called upon to perceive fine detail. In the case of outdoor target-shooting such glasses have proved very helpful; however, in such cases the decrease in glare is not due, predominantly at least, to any inherent virtue in the yellow or yellow-green light, but is due chiefly to the great reduction in brightness of the broad expanse of visible blue sky and the accompanying decrease in the luminous flux entering the eye. The author has suggested the use of a greenish-yellow light for illuminating indoor rifle-ranges owing to the fact that for equal brightnesses of the targets and their surroundings (and therefore perhaps approximately equal conditions of glare) the targets can be seen more clearly, the increased definition being due in this case to the less extended spectral character of the light. No definite data is available from such installations. Protecting glasses will not be effective in the same manner indoors as outdoors, owing to the absence of a broad area of high brightness which is present in the latter case. When yellow or yellow-green glasses are used for distant vision, with or without field glasses, the increase in the clearness of details is quite apparent. One reason for this is the partial elimination of the bluish haze which is more or less effective in obliterating distant details. Some of these effects are not directly

connected with the problems of lighting but nevertheless are often confused and misinterpreted.

Some time ago Dr. P. W. Cobb showed that a bright light source in the field of view was glaring even when the image of this source fell on the blind spot of the retina. He attributed the glare due to scattered light in the eye. It has been suggested that blue light might be more glaring than yellow light because of the greater scattering of the blue rays by fine particles as discussed later. However, diffusing media differ in their selective scattering of rays of light and little is known about the selective scattering of the sclerotica or white exterior coat of the eyeball.

The advantage of using yellow or yellow-green glasses has been shown elsewhere.[3] An acuity object was set up on a clear day in the shade of a building in such a position that a large sky area was visible to the observer. Visual acuity readings were made as rapidly as possible and after three minutes had elapsed yellow-green glasses were quickly placed before the eyes and the readings were continued. At the end of three minutes these glasses were removed and readings were made as before. At the beginning of the observations only a slight sensation of glare was experienced; however, as soon as acuity observations were begun the glare became very evident and rapidly grew painful. Acuity was always better when the colored glasses were before the eyes and during the latter part of the experiment, which lasted 18 minutes, it was indeed a great relief to wear the yellow-green glasses. The absorption coefficient of these glasses was about 50 per cent. yet acuity was better with this reduced illumination than with the total light and the discomfort due to glare was practically eliminated. This experiment showed conclusively the reduction of glare attending the reduction in the brightness of the sky area.

The foregoing provides an example of the ease with which confusing conditions are brought about. It might be argued that the decrease in the amount of *blue* light due to a reduction in the brightness of the sky area was responsible for the reduction of glare. However, it is quite certain that this excessive glare

[3] Luckiesh, M., Safeguarding the Eyesight of School Children; TRANS. I. E. S., p. 181, No. 2, 1915.

was due to the broad expanse of bright sky in the visual field and was not related appreciably to the color. As previously stated there are no definite data available relating to glare and the color or spectral character of the illuminant.

Fatigue.—Here again definite data are lacking for quite the same reasons as found in the measurement of glare, namely the vagueness of the condition and the criteria and the absence of an approved and thoroughly tested method. It is perhaps safe to state that there is a general opinion that ordinary artificial light is more productive of fatigue than ordinary daylight. The author is inclined to believe that sufficient weight has not often been given to the fact that artificial light is usually judged after the eyes have done a day's work under daylight. It has been contended that the greater energy absorption in the eye media[4] per unit of light for ordinary yellowish artificial illuminants than for daylight accounts for eye-fatigue under artificial light. Little account seems to have been taken of the much greater intensities of illumination usually experienced in daytime. If this contention is correct there should be plenty of evidence of eye-fatigue due to absorption of energy in many cases of daylighting. Inasmuch as this point has not been proved and as there are no experimental data available that throw much light upon the subject, it is futile to discuss it further.

It has been contended[5] that yellow and orange lights at high intensities are more fatiguing than green and grenish-blue lights. It has been suggested by some that this result obtains because the yellow rays are more effective in bleaching the visual purple than rays of other wave-lengths. There is much to be learned about this process and several problems must be investigated before such a conclusion is tenable. For instance, the relation of the bleaching action to the amount of light-sensation produced and to fatigue must be known before such a contention can be considered more than a hypothesis.

The statement is often made that yellow light is "easier on the eyes" than white light. Usually this is applied to the use of yellow paper; and, based on this premise, certain books have

[4] Luckiesh, M., Radiant Energy and the Eye; *Elec. World*, Oct. 25, 1913. Energy Density in the Eye-Media; *Elec. World*, 1915.

[5] Steinmetz, C. P., Radiation, Light and Illumination; 1909, p. 265.

been printed on yellow paper. There are so many variables that it is impossible to draw definite conclusions from the available data. However, it is well to distinguish between the two conditions, namely, black type on a yellow paper illuminated by white light and black type on white paper illuminated by yellow light. In general there will be a difference in the contrast ratios between the type and backgrounds in the two cases. The ink may be assumed to reflect light non-selectively and therefore, for equal brightnesses of the type in the two cases, the brightnesses of the backgrounds, one of which selectively reflects light, will be unequal. The contrast ratio is probably of some importance from the standpoint of fatigue, but there are no data available regarding this point.

The author has used artificial daylight for several years for desk lighting and it has been his experience that it is less fatiguing than the light from a tungsten incandescent lamp. This is especially evident when the daylight must be reinforced by artificial light. This experiment was carried further by using clear tungsten lamps and tungsten lamps with medium and dense yellow bulbs for several hours of reading on a great many evenings. It is certain that the deep yellow light was more fatiguing than the light from a clear tungsten lamp and that the latter seemed to be more fatiguing than the daylight. Another observer drew the same general conclusions. The experiments were made with the yellow lamps versus the clear lamps in the evening, but the comparisons of the artificial daylight and tungsten light were made in daytime under ordinary working conditions. The lighting conditions such as the distribution of light, position of the book and observer, etc., were such as would be termed satisfactory. It is recognized that such experiments are not of the character that would be pronounced conclusive, but it appears that such data should be gathered and recorded. As long as a simple method for testing eye fatigue is unavailable such observations as noted above must govern our practise and in all events they will be available for future summaries.

PENETRATING POWER.

Inasmuch as blue rays and others of short wave-length are scattered more than the rays of longer wave-length it is in-

teresting to consider the penetrating power of yellow light as compared with that of other lights. It is well known that smoke consisting of fine particles appears bluish in color while its shadow on a white surface is of a reddish hue. The setting sun appears red owing to the partial absorption of the visible rays of short wave-lengths by the smoke, dust, etc., in the atmosphere. This absorption is produced largely by scattering the blue rays more than the rays of longer wave-length with the result that the skylight, which is scattered sunlight, appears predominantly blue in color. In the same manner the familiar haze in the distance appears blue. It is thus seen that the yellow light will penetrate through a greater thickness of ordinary atmosphere than white or bluish light. Obviously deep yellow and red lights if they could be produced at a high efficiency would be quite satisfactory for signals that must penetrate a dust and smoke laden atmosphere. In experiments conducted on a clear night it has been found[6] that there was no difference in the penetrating power of tungsten and carbon incandescent electric lights for distances of a mile.

In the case of headlights another condition is of interest, namely that when the observer is behind the headlight. In this case, the condition is different from that of an observer in the distance trying to distinguish the signal light. An automobile or locomotive driver uses the light for illuminating the pathway and if a considerable portion of the light be scattered by fog, smoke, or dust, it should be more difficult to see through the illuminated veil than in the case of little or no scattering of light. In fact, the reduction in the ability to see is very likely due more to this luminous veil than to the actual loss of light in the projected beam. This condition is reproduced by painting a screen door white and attempting to see beyond it. It is well known that it is difficult to see into a room when such a screen is highly illuminated by daylight on the side toward the observer. Owing to the fact that visible rays of short wave-lengths are scattered more than the yellow, orange and red rays, it appears that the luminous veil in an atmosphere laden with fog, smoke, or fine dust would be less apparent and less liable to obscure vision in

[6] Paterson and Dudding, Visibility of Point Sources, National Physical Laboratory, England; Abstract in *Elec. World*, 1913, vol. 67, p. 266.

the case of a yellow illuminant than in the case of one containing a relatively greater amount of rays of the shorter wavelengths. Such experiments are difficult to perform owing to the impossibility of obtaining constant conditions out of doors and to the absence of a simple and rapid method for making the observations. However, the author experimented with tungsten lamps in automobile headlights using a greenish-yellow glass over one headlight and a clear glass over the other. On several foggy nights the experiments were made and although the screens were used interchangeably on the two lamps the four observers concluded that distant objects in the fog were more easily seen by means of the greenish yellow light notwithstanding the fact that the luminous intensity of this beam was 25 per cent. lower than that of the 'white' beam through the clear screen.

Based upon the forgoing principle several different types of headlights have been constructed by various companies. These include gold-plated reflectors, greenish-yellow glass reflectors backed with a silver coating, yellow-green bulbs for tungsten lamps, and greenish-yellow lenses in the aperture of the reflector. It appears that the latter scheme has all the advantages possessed by the others and the additional advantage of simplicity. Of course there may be cases where a glass screen can not be used in the aperture, such as in the extremely powerful searchlights. In such cases the observer could wear the screens before his eyes.

The phenomenon known as the Purkinje effect has often been misinterpreted in considering the penetrating power of illuminants. It is true that at low intensities of illumination the visible rays of short wave-lengths possess a relatively greater illuminating value than the rays of longer wave-lengths, as compared with their relative values at high intensities. This fact is perhaps worthy of attention, but it should be noted that the Purkinje phenomenon is usually studied with the entire retina dark adapted. This is not in general the condition found in practise because the foreground, especially from the point of view of an automobile or locomotive driver, is usually of brightnesses well above the Purkinje region. Some investigators have found the Purkinje phenomenon to be much less marked in the case of the photometric field being surrounded by a field of moderate brightness.

It is interesting to note that the visibility of point sources of light in clear atmosphere has been shown[6] to vary directly as the candlepower and inversely as the square of the distance. Further, in the case of signals it must be remembered that the central region of the retina, where objects are seen clearly, is more sensitive to yellow light than to blue light.

ESTHETIC VALUE.

The esthetic value of colors is quite a matter of taste; therefore it is not surprising to find a diversity of opinion. For this reason it is difficult to discuss this phase of the subject. Too often the illuminating engineer fails to distinguish between matters of taste and scientific facts that are not affective in nature. So that it appears profitable to discuss this subject briefly in order to emphasize this point. The history of the esthetic value of yellow is interesting as it is for colors in general. It is of particular interest inasmuch as artificial illuminants were for many years of a yellowish hue and even to-day most of the illuminants that are used where the esthetic taste is important are quite yellow as compared with daylight. While there are problems pertaining to the affective value of colors awaiting solution, it appears to the author that the chief object of the lighting expert in dealing with the esthetic side of color in lighting should be to ascertain, and satisfy if possible, the esthetic taste of his client rather than his own. It is the client who must be satisfied and it is the client who is obliged to live amid the surroundings whose appearance is largely under the control of the lighting specialist. Experience shows that illuminants of many tints find a place in lighting owing to the diversity of taste which actually exists. If a person interested in lighting prefers the "warmer" tints of the older illuminants he should recognize that this is a question of personal taste and should not enforce upon others a condition which is strictly a matter of taste. Likewise those who believe that modern illuminants should be altered in the other direction because they prefer artificial daylight should take care that they distinguish between those cases which require light of a daylight quality for scientific reasons and those which are governed only by the esthetic sense.

[6] Paterson and Dudding. Visibility of Point Sources, National Physical Laboratory, England; Abstract in *Elec. World*, 1913, vol. 67, p. 266.

There are many interesting, conflicting, and amusing statements to be found regarding the psychological (and physiological) influence of color. It is quite permissible to express personal opinions and convictions regarding the psychological influence of color, but care should be taken to label these "personal convictions" in order that those less familiar with the subject may not take the statements too seriously and assume that they are generally applicable. A common mistake is made in expressing a conclusion involving psychological influence of a certain condition of lighting and ascribing a reason which can be shown to be unjustified. It has been stated by a lighting specialist that the "white" light of the tungsten lamp caused persons to be depressed, to have a headache or to have the blues. It is a remarkable fact that those persons enjoy life at all considering that they are compelled to live in daylight for a large portion of their time. Of course the appearance of a color is very largely influenced by its environment and contrast is an important factor. How much a purely imaginary contrast can effect personal taste the author is unable to state; but, if the person who is depressed by tungsten light owing to its "whiteness" is mentally comparing its color with that of the carbon lamp or another old illuminant, it is quite likely that the tungsten lamp appears unduly white. But why should the older illuminants be taken as the standard for comparison? If that person should compare carbon and tungsten lamps side by side with daylight relatively little difference will be seen between the colors of the kerosene, carbon and tungsten lights. It is strange indeed to hear so little complaining regarding the unesthetic color of daylight. However, influenced by these various appeals for "warmer" illuminants, one is often inclined to believe that the Creator made a mistake in designing the first and most universal illuminant. Perhaps He designed the best utilitarian illuminant leaving it to man, as he rose in the scale of intelligence, and developed an esthetic sense, to provide his own luxuries.

In a recent paper in the TRANSACTIONS the use of amber glass was very much in evidence for altering tungsten light to a "warmer" tint. Amber glass will not alter tungsten light to match any of the older illuminants and while it may be preferred

by many persons it has a greenish tinge that is objectionable to many. Thin amber glass is nearly a lemon yellow and the dense specimens become less greenish when viewed in tungsten light, but at no density will the ordinary amber glass match any of the older illuminants. Therefore, if light of an amber color is preferred it is not because it imitates the color of older illuminants. Here it may be of interest to refer briefly to some experiments conducted in a study of color preference.[7] A group of fifteen fairly saturated colored papers (representing the whole range of the spectrum) each 4 inches (10.16 cm.) square, were presented to fifteen observers who were instructed to choose the colors in the order in which they preferred them. Among other instructions each observer was asked to choose the colors for color's sake alone by isolating each color in his mind. In fact, he was told to "live" and to "see" each color individually until he was prepared to make his choice. Both in tungsten light and daylight (the separate experiments being conducted usually several weeks apart) the lemon yellow ranked last and the more reddish yellows ranked about midway in the preference order. The lemon yellow was placed last in the preference order by nearly every observer. These data are not presented as proof that the average person does not like an amber color because it is a long step from this experiment to lighting conditions, but rather to illustrate that the esthetic or affective values of colors can be studied with groups of persons.

The author has experimented with clear tungsten light, artificial daylight, rose, yellow, blue, red, and amber lights in the home, and while some of these results are outside the scope of this paper, it may be of interest to record his personal conclusions. Clear tungsten light was found to be satisfactory in most cases when the glass shade or accessory was of a yellowish tint. The light itself was satisfactory as far as the appearance of most objects was concerned. Especially in a shower over the dining room table it was satisfactory but largely due to the fact that the glass shades which concealed the lamps were a deep yellow in color providing a low intensity yellow light for illuminating the walls and ceiling and permitting unaltered light to illuminate the table. The artificial daylight lamps were pleas-

[7] Luckiesh, M., Color and Its Applications, Fig. 77; *Scientific American*, June 26, 1915.

ing in the same fixture and also in a reading lamp with a yellow silk shade the direct light being unaltered in color. In a white semi-indirect bowl in the living room slightly rose-tinted lamps were used for several months. These were found to be definitely unrestful and somewhat irritating. The yellow lamps which were carefully made to match a kerosene flame were the most satisfactory for the general illumination in the living room for conversational purposes, but not for reading. The deep blue light which was used to illuminate the ceiling of the dining room in order to roughly imitate out of doors was quite depressing. The red, as is commonly experienced, was highly unsatisfactory for general illumination even at low intensity and low saturation. The amber light was not as satisfactory as the unsaturated yellow which simulated the kerosene flame. These conclusions were quite definite in all these cases and were arrived at through many experiments and many months of observation under ordinary conditions in the home. It should be noted that the rugs and paintings in the room lost much of their beauty under the yellow illuminants which suggested the possibility of using tungsten lamps with both clear and yellow bulbs on separate circuits. This scheme was tried and has been used for a year with considerable satisfaction.

SIMULATING OLD ILLUMINANTS.

The present efficiency of illuminants makes it possible to vary their color to suit the requirements by the use of colored screens and yet enjoy the advantage of a fairly high efficiency. The quality of the tungsten light has been altered to match in spectral character various kinds of daylight. Owing to the fact that many have expressed a desire to simulate the color of the older illuminants, considerable attention[8] has been given to this subject. The transmission of ideal screens for converting the light from vacuum tungsten lamps of various luminous efficiencies to the same spectral character of the old carbon incandescent lamps (3.1 watts per mean horizontal candle) and of the kerosene flame have been computed and the resulting luminous efficiencies have been determined. In Fig. 1 Curve C_T represents the transmission

[8] Luckiesh, M., Simulating Old Illuminants; *Elec. Review* and W. E., July 24, 1915, p. 161.

of the ideal screens for total light for converting the light from vacuum tungsten lamps operating at various efficiencies into light of the same spectral character as that of the carbon incandescent

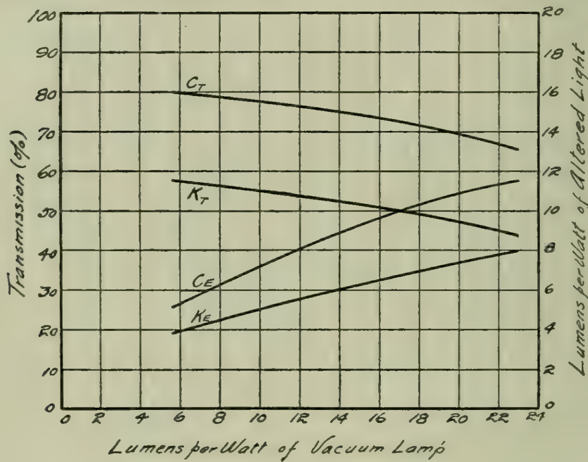

Fig. 1.—Showing the transmission of colored screens for use with the vacuum tungsten lamps for simulating old illuminants; also showing the luminous efficiency of the altered light.

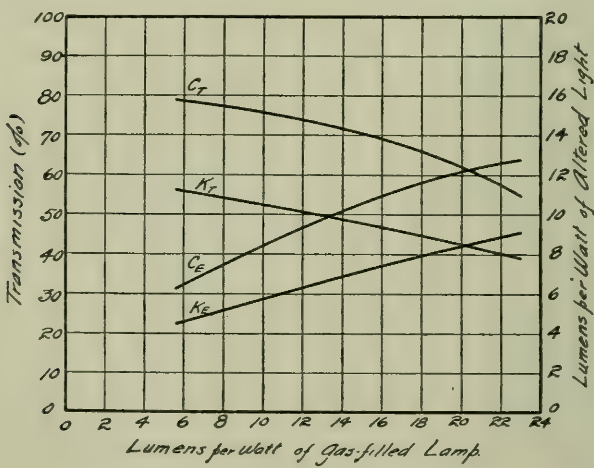

Fig. 2.—Data similar to that in Fig. 1 but for the gas-filled lamp.

lamp. Curve K_T is a corresponding curve for the ideal screens which convert the light from vacuum tungsten lamps into light of the same spectral character as the kerosene flame. On com-

bining the transmission of the ideal screen in any case with the luminous efficiency of the unscreened illuminant, the luminous efficiency of the altered light is obtained. Curve C_E represents the final luminous efficiencies of the vacuum tungsten lamp after it has been screened to match a carbon lamp in color. K_E shows a similar data when the tungsten lamp has been screened to match the kerosene flame. In Fig. 2 the corresponding data are given for the gas-filled lamp.

In Fig. 3 curve C represents the spectral transmission curve of the ideal screen for altering the light from a vacuum tungsten lamp, operating at 7.9 lumens per watt, to a spectral match with

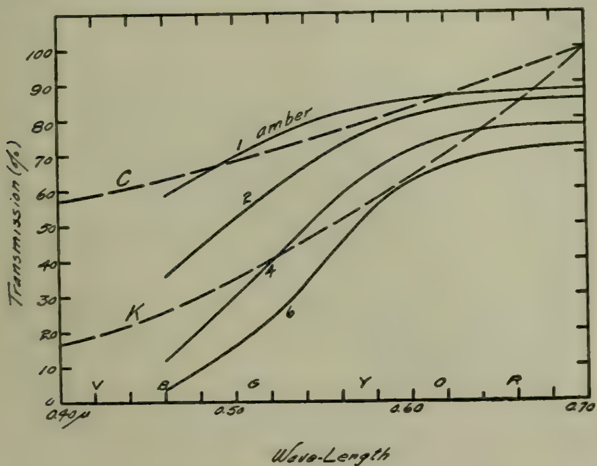

Fig. 3.—Ideal screens for tungsten lamp (vacuum) operating at 7.9 lumens per watt compared with common amber of various densities.

the light from the carbon incandescent lamp under consideration between 0.40μ and 0.70μ, the transmission being assumed to be 100 per cent. at 0.70μ, the practical long-wave limit of the visible spectrum. Curve K is a similar curve of an ideal screen for matching the spectrum of the kerosene flame. Curves C′ and K′ in Fig. 4 are similar curves of corresponding ideal screens for the gas-filled tungsten lamp operating at 22 lumens per watt. Similar computations have been made for tungsten lamps operating at various efficiencies, which data have been used in plotting the curves shown in Figs. 1 and 2.

In producing practical colored screens for the foregoing pur-

poses the obvious beginning is to use a yellow pigment. No permanent pigment has been found which alone will suffice. This is not surprising to one familiar with coloring elements, but it has not usually been recognized in practise. Most so-called yellow pigments have a greenish tinge in the lesser densities and the author is not aware of any permanent yellow pigment that matches a spectral yellow in hue, or that at any density will, when used with the tungsten lamp, match the unsaturated yellow of the old illuminants. Usually a pigment which is given the name of amber is considered satisfactory. Of a number of yellow pigments examined (and these represent perhaps all the permanent

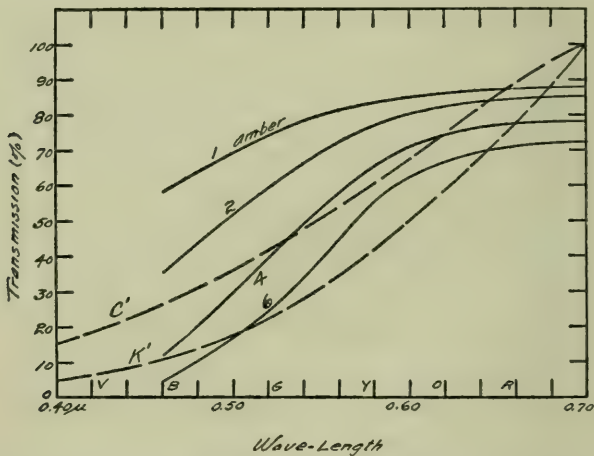

Fig. 4.—Ideal screens for tungsten lamp (gas-filled) operating at 22 lumens per watt compared with common amber of various densities.

yellow pigments) none was found to be satisfactory alone. An example which is approximately representative of this group of yellow pigments is shown by the so-called amber glass of four different densities in Figs. 3 and 4. The numbers on the curves represent the relative amounts of coloring matter present per unit of surface area of the amber glasses. In general the glasses are seen to transmit green rays too freely. In order to make this point clear the spectral transmission curves of the ideal screens C and K in Fig. 3 have been plotted equal to unity of all wavelengths in Figs. 5 and 6 respectively, and the transmission of the amber glasses were made equal to unity at 0.70μ, the practical

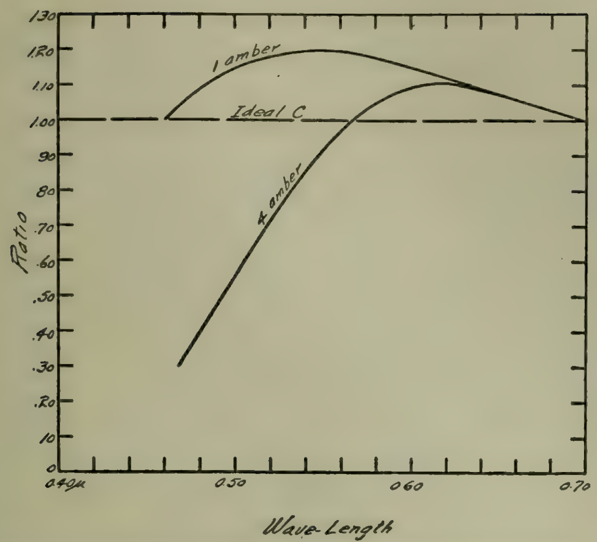

Fig. 5.—Showing the ratio of transmission of amber glass (various densities) to that of an ideal screen for converting the light from a tungsten lamp operating at 7.9 lumens per watt to the same spectral character as that from the carbon lamp.

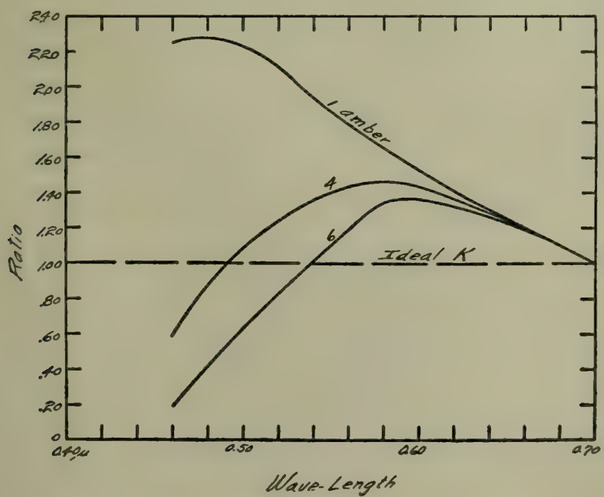

Fig. 6.—Showing the ratio of transmission of amber glass (various densities) to that of an ideal screen for converting the light from a tungsten lamp operating at 7.9 lumens per watt to the same spectral character as that from the kerosene flame.

limit of the visible spectrum. It is thus seen that no density of a so-called amber glass will suffice for the purpose under consideration.

These curves for an average yellow pigment have been presented to illustrate that it is not an extremely simple matter to simulate the color of the older illuminants by using colored screens with tungsten lamps. However, inasmuch as the requirements do not demand more than a close approximation, one familiar with pigments and color mixture readily can produce a proper coloring. The match can be subjective if the spectral character of the altered light does not vary too much from the illuminants to be matched. Satisfactory colorings have been made for matching the kerosene flame by means of the tungsten lamp and on viewing this lamp in comparison with the common amber lamps the truth of the foregoing is strikingly evident. That is, the ordinary amber lamps appear very different from the unsaturated yellow of the properly colored lamps.

It has long appeared to the author that illuminating glassware which largely is practically colorless, if properly tinted an unsaturated yellow instead of the common greenish-yellow, would meet with the approval of many users. For instance, the appearance of a semi-indirect bowl of the proper tint would satisfy the esthetic taste of those who desire the "warmer" tints, and if the walls and ceiling were properly tinted clear tungsten lamps would be satisfactory. It has been shown[9] that the color of the surroundings alter considerably the useful light by selective reflection. In fact it was shown that with the so-called indirect and semi-indirect systems a yellow tinge in the color of the walls and ceiling altered the tungsten light which reached the useful plane to a yellowish hue more saturated than that of the older illuminants. This alteration by selective reflection can be utilized in many cases of so-called indirect and semi-indirect systems and in the case of the latter the bowl can be properly tinted. In the case of direct units it is more difficult to obtain the "warmer" light without coloring the lamp. However, as shown in the case of the shower, if the shades are deep enough and of the desired color the results can be made pleasing. However, it is not the

[9] Luckiesh, M., The Influence of Colored Surroundings on the Color of the Useful Light; TRANS. I. E. S.

intention of the author to discuss fully this phase of the subject.

An attempt has been made to point out briefly the place of yellow light in the problems of lighting and vision. There are many conflicting opinions and a lack of data on some questions. The chief reasons for the confusion appears to be due to misinterpretation of results by the lack of careful analysis of the conditions. It has appeared worth while to record the results that have been obtained, to summarize the opinions and conclusions of others and to discuss briefly the theory underlying certain phenomena. Many of the questions involved in the foregoing discussion have arisen from time to time and it is to be hoped data will be presented by others which will aid in clarifying the confusion now existing. It is further to be hoped that the illuminating engineer will be more analytical in drawing conclusions and recording observations concerning such phenomena as are discussed in the foregoing paragraphs.

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DISCUSSION.

Mr. J. R. Cravath: I am very glad Mr. Luckiesh has exploded a bomb under a lot of nonsense that has been talked about matters of color in connection with illumination engineering, and shown where the line of demarcation is between taste and scientific fact. There has been a great deal said about color which is purely a matter of personal opinion.

Dr. J. W. Schereschewsky: It seems to me that, considering the matter on physiological grounds, there can be no reason whatever for asking for a yellowish tone in artificial illuminants. The nearer they approximate the spectral composition of day-

light, the better they are for seeing purposes. I think possibly one reason why we have found kerosene light, for instance, agreeable, is that at the low intensities at which kerosene lights are usually employed, the eye perhaps finds it a little more able to adapt itself to the luminous intensity involved. It seems perhaps—I don't know—that this is a subject for future investigation. There is some internal evidence to the effect that the shorter wave-lengths will tend to produce a state of hyperadaptation, that they are stimulators of adaptation. That is to say, when we have high intensities, we will get a little better adaptation to those intensities if the percentage of blue light in the source approximates daylight. On the other hand, in very high intensities in which the yellow component is more in evidence, there may not be that physiological stimulus to complete adaptation which blue wave-length seem to bring forth. On the other hand, where we use low intensities, as in the case of kerosene light, the eye is perhaps a little bit more sensitive to the light under those circumstances; and consequently with that low intensity, we find the light agreeable to read by; but I think on the whole that we are advancing toward the natural trend which illuminating engineering ought to take, where our whole aim will be to reproduce, as nearly as we can, the natural composition of daylight and raise the intensity. I cannot see any real object in trying to produce warm tones except simply the psychological association with firelight which was the symbol for warmth and comfort in the early days when men had a much harder struggle to live than they have now.

Mr. G. H. Stickney: In practical illuminating engineering, questions relating to the color of light arise in quite a number of problems. It is not surprising that there is more or less confusion as to whether the color differences affect the physiological action of the eyes or the mental processes, especially as both are quite susceptible to suggestion. This is rather borne out by the differences of opinion among different individuals or communities, while those who are closely associated seem inclined to agree one way or another.

In street lighting, for example, some people think they can see much better by a white light than by one having a slightly yellow

tint. On the other hand, others claim they can see fully as well by the yellow tinted light and prefer it on account of its pleasing color. Personally, I have been unable to discover any appreciable difference, traceable to color, in the seeing value of light from the high efficiency incandescent lamps or the white or even slightly bluish lights. I believe that such differences are more readily explained by variations in intensity, direction or glare.

Again, we sometimes hear that white light from street lamps is preferable for use in conjunction with incandescent lighted show windows. My own observation has been that the most pleasing effect is obtained when both are approximately the same color. When two such colors of light are mingled so as to emphasize the simultaneous contrast, I have noticed that if the white light is more brilliant, the yellow light looks dingy; or if the yellow light predominates it looks warm and pleasing, while the white lights appear cold and blue. Still I am not sure but what there are conditions under which it might be desirable to combine the two colors of light.

In store lighting we sometimes find a compromise necessary. White light is unquestionably preferable for the selection of colored materials for daylight use. On the other hand, most store managers seem to prefer the appearance of the store under incandescent illumination, and even where colored materials are sold they often consider the warm homelike effect of the yellow tinted light more important than the degree of color matching quality obtainable with any practical illuminants.

Another phase of this question arises in connection with headlights for automobiles, etc. It has sometimes been thought advisable to use yellow screens in connection with incandescent headlights to reduce the glare. This, of course. has to be considered from two standpoints. To the approaching observer glare does not seem to be reduced to any greater extent than has the illumination; on the other hand, to the driver behind the headlights there is undoubtedly a reduction of halation especially on damp or foggy nights. Beyond the reduction of this diffractive halation, I doubt if there is any advantage to be gained in cutting down the illumination by the use of any form of color subtractive screen.

A MEMBER: Some fifteen years ago I carried on a series of experiments with a view to determining the best light for the eyes, taking as the criterion, the ease with which reading could be done, and after going over quite a range of colors, I decided on the yellow-green. Experiments were carried on in a closed room at night and with a light source out of the range of vision.

DR. J. W. SCHERESCHEWSKY: I forgot to mention the range of personal preference of individuals with regard to the refraction of the eye. It seems to me that the refraction of the eye often has a marked influence on the kind of light and the kind of colors individuals prefer. Persons who have a tendency to hyperopia are naturally inclined to prefer colors at the short end of the spectrum, whereas myopes prefer longer wave-lengths which can be focused with greater ease on the retina; so I think that the preference really lies in the state of refraction of the eye of the individual concerned.

MR. W. A. DURGIN: If the use of white or yellow light is only a matter of personal preference, as this paper rather indicates, the immediate problem of light supply becomes a determination of the present preponderance of that preference. My personal experience seems to indicate a majority choice of yellow light. In the offices of Commonwealth Edison Company of Chicago, where 1,200 employees work under a distinctly yellow flux, at least sixty have come forward with expressions of approval, whereas none has expressed dissatisfaction. This, however, is only an indication. Widespread observation is needed, and the accumulation of such preference data should be made a part of all illumination testing programs.

DR. CHARLES P. STEINMETZ: The subject matter of Mr. Luckiesh's paper on the effect of the quality of color on the ease of the eye is a very interesting one and very well worth careful consideration and study, especially since the experimental evidence of different observers not infrequently directly contradicts, and even the conclusions of one and the same observer under different conditions are not infrequently entirely contradictory. Now the reason, the way I look at it, is, that the easiest light is the light that is least fatiguing to the eye. Now at times it depends on the conditions, whether fatigue will occur with one

color of light or another color. I do not believe there is any particular color of light which, by itself, is less or more fatiguing than another, but the question depends entirely on the relation of the color of the light to the color of the objects which are distinguished and the purpose for which we desire to distinguish them. If there is any special quality in the light by itself, we would naturally expect that in the middle of the spectrum, which is about between 53 and 54 microcentimeters, the light would be the easiest. Now then, we use light to distinguish, and where the observer of the light is to distinguish objects sharply, as for instance, in reading and calculating and doing exact work, there naturally that light will be the least fatiguing which gives the sharpest distinction, that is, which exaggerates contrast; and that, indoors, is a short wave light, the white or the bluish green. Where the purpose is to rest the eye, that is, not to give strong contrast and thereby irritate the eye by continuously seeing irrelevant things, but merely to show enough contrast to be able to walk around and see the room, as for general indoor illumination, there the light will be the least fatiguing which reduces the contrast. Now you see that depends on whether you arrange your experiment in trying the restfulness of light under conditions of exact detail work or under conditions of resting after the day's work in your room; obviously exactly opposite conclusions about the color of the light may be obtained. Furthermore, the restful light, which reduces contrast so much that when you are nervous or irritated, you feel that it is restful, will usually be the long wave-light, yellow or orange-yellow, because the predominant doors, where the predominant colors are blue and green, the was pointed out by Mr. Luckiesh is very irritating because it is intensified by contrast with the different kinds of light; while out doors, whwere the predominant colors are blue and green, the short waves, the blue sky is not irritating, while if, under certain atmospheric conditions you have a yellowish sky, you feel uncomfortable. You cannot speak of a definite color of light as having a definite effect, but it is all relative. Monochromatic light allows the eye to focus, because you get a definite focus, but where a definite distinction is not wanted, monochromatic light is not wanted; otherwise chromatic, light, by distorting the color effect, is irritating to the eye; it means, in short, that the

effect of color of light, in its effect on the eye, is entirely a relative condition dependent on the surrounding objects in their color character and the purposes for which you desire to see.

MR. M. LUCKIESH (In reply): I gathered together these conflicting conclusions with the hope that with closer attention by lighting engineers the questions will be answered eventually. The last sentence in the paper brings forth a vital point in future procedure. There is little to add to the discussions by various members. I should like to bring out one point in connection with Mr. Durgin's remarks. He has exhibited here a unit consisting of amber glass cased with opal glass. When the unit is lighted the bowl appears a decidedly amber color. He mentioned that quite a number of employees "have come forward with expressions of approval wheras none has expressed dissatisfaction." Inasmuch as only a portion of the light (the direct component) is altered by the amber glass, I wonder whether the employees in expressing approval were influenced by the color of the light unit or the actual color of the light which they use. These are probably two different colors, the light which they use consisting of the altered direct component plus the indirect component which is altered by reflection from the walls and ceiling. I have shown that the alteration due to colored surroundings is considerable (TRANS. I. E. S., vol. 8, 1913, p. 62). This illustrates a point from which much confusion may arise. A danger in using the opinions of laymen is that these opinions may be influenced, as is possible in this case, by the impressions gained by looking at the lighting unit instead of through a consideration of the light that actually reaches their working planes. It may be in this case that no such errors exist; nevertheless, this is a very common error among those who use light. In considering this entire subject, one should be careful to make a complete analysis of the conditions and when using the opinions of laymen, one should be certain that the opinions are based upon such an analysis. Another danger in using opinions of laymen is that there is often a decided tendency of such observers to form opinions that they believe are desired by their superiors. These are examples of pitfalls that are well known and thoroughly considered by the investigator.

THE EFFECTIVE ILLUMINATION OF STREETS.*

BY PRESTON S. MILLAR.

Synopsis: This paper mentions the dependence of effectiveness in street lighting upon municipal appropriations and efficient lamps, but discusses more particularly those aspects of effectiveness which are dependent upon skilful utilization of the light to produce the most effective illumination. There are included a classification of streets, a statement of the objects of street lighting and the elements of vision under street lighting conditions. The paper emphasizes three considerations which are sometimes neglected in street lighting discussions; namely, the silhouette effect, specular reflection from street pavements, and glare. The remainder of the paper is given over to a presentation of the variables upon which the effectiveness of street illumination depends, and upon the influence which each feature of the installation exercises through these several variables. As a part of this discussion illuminating efficiency values for the several modern street illuminants are given. The appendix includes statistics and photographs of some very recent installations which illustrate the latest trend in street lighting.

Improvement in street lighting involves (1) larger municipal appropriations; (2) more efficient lamps and accessories; (3) greater skill in application.

FACTORS INFLUENCING IMPROVEMENTS.

Larger Municipal Appropriations.—The public is gradually becoming acquainted with the advantages of more liberal use of light. Use of the streets at night is becoming more general throughout a greater number of hours. Requirements for good street lighting are becoming greater as traffic becomes denser and as traffic speed increases. Also the advertising value of extensively employed light is commanding appreciation in mercantile lines. These things combined are leading to larger municipal appropriations. Larger appropriations mean betterment in street illumination because the mere addition of lamps with no increase in lighting efficiency and no greater skill in application usually improves conditions. The greatest single obstacle to satisfactory street illumination is lack of funds.

More Efficient Lamps and Accessories.—The last two years have witnessed increases of 25 to 50 per cent. in efficiencies of street illuminants, the gas-filled, tungsten incandescent lamp and the magnetite arc lamp having progressed contemporaneously. At the present time in the magnetite lamp of medium and high

* A paper read at a joint meeting of the American Institute of Electrical Engineers and the Illuminating Engineering Society, at a convention of the former organization held June 29 to July 2, 1915, at Deer Park, Md.

power, in the gas-filled lamp of low, medium and high power, and in the flame arc lamp of high power there are available illuminants having efficiencies four or five times greater than those of various types of enclosed carbon arc lamps which were the principal street illuminants in this country a few years ago. Some advance has been made also in the design of lamp equipments, notable among which are the prismatic refractor and a variety of light density translucent glassware which combines fairly good diffusion with high transmission. These improvements in the materials of street illumination combined with the increased sums which municipalities are appropriating make possible a very general improvement in street lighting.

Skill in Application.—Recently installed systems are almost invariably superior to the systems which they replace. Usually the improvement is due in part to greater skill on the part of the engineers in charge. City engineers, central station engineers and manufacturers are better acquainted with the problems and have acquired more skill in meeting them. The result is street illumination of greater effectiveness. Notwithstanding this advance there are but few principles of street illumination which are regarded as thoroughly established. Although the subject has received perhaps more than a fair share of discussion and study, it is still enveloped in much uncertainty. In the literature and in practise there is much which indicates differences of opinion in regard to principles of fundamental importance. It must be admitted that progress in the conception of correct principles is slow. Yet there is progress and it may be that by the time most street lighting is made good, those of us who talk and write of the principles may reach an agreement as to what constitutes good street lighting.

It is the purpose of this paper to discuss the variables of street illumination and the principles underlying the best use of modern illuminants and accessories under modern conditions in this country. Therefore, matters pertaining more especially to the third factor entering into improvement in street illumination, as enumerated in the opening paragraph[1], will be discussed first.

[1] This paper may be regarded as a continuation of the discussion presented by the author before the 1910 convention of the Illuminating Engineering Society under the title "Some Neglected Considerations Pertaining to Street Illumination". TRANS. I. E. S. Vol. v, p. 653.

CLASSIFICATION OF STREETS.

For the purposes of this discussion the following classification of streets is adopted:

Class	Description
1a	Metropolitan thoroughfares of greatest distinction.
1b	Important city streets largely traveled at night.
2a	Business streets not largely traversed at night.
2b	City residential streets.
3a	Suburban residental streets.
3b	Suburban thoroughfares.

It will be apparent that requirements for street illumination are diverse as among these different classes of streets. For example, the 1a class of streets is distinguished by a requirement for dignified, pleasing fixtures and for lamps and illumination which should be of fairly high intensity, lighting building fronts as well as street. Streets of the 1b class are likely to be characterized by much show-window and sign lighting which augments the street illumination during the hours of greatest traffic. Here intensities are likely to be highest, and the ordinary fundamental requirements of street lighting are supplemented by the desirability for recognizing acquaintances in the passing throng and for detailed vision, approaching that common to interiors at night.

In streets of the 2a class a moderate intensity of illumination which lights building fronts as well as street is customary. Policing purposes and good seeing conditions for the occasional pedestrian are the principal desiderata. In streets of the 2b class it is usually desirable to keep the light upon the street surface, avoiding brilliant illumination of the upper stories of residence fronts and providing fairly good lighting for the low density vehicular and pedestrian traffic.

In streets of the 3a class it is likewise desirable to keep the light upon the street, illuminating the sidewalks well to serve the purposes of pedestrians. In streets of the 3b class, which are the important automobile highways connecting populous centers, the principal requirement is that of the automobile driver. Here the most difficult problems of street illumination are encountered.

The discussion in this paper is applicable in varying degree to streets of these six classes.

OBJECTS OF STREET ILLUMINATION.

From several points of view the objects of street illumination may be stated in somewhat different ways. The point of view of the motorist differs from that of the pedestrian, which in turn differs from that of the police commissioner and from that of the merchant. When, however, one assembles the considerations growing out of all these viewpoints, those of first importance appear to fall within the comprehensive classification presented by the National Electric Light Association Street Lighting Committee in 1914 which is as follows:

Fundamental Purposes to be Served by Street Illumination.

1. Discernment of large objects in the street and on the sidewalk.
2. Discernment of surface irregularities in the street and on the sidewalk.
3. Good general appearance of the lighted street.

It would appear that in proportion as these three purposes are served the street illumination will be regarded as satisfactory, and it may be concluded that no street lighting installation which serves these three purposes reasonably well can be regarded as unsatisfactory. The weight to be given each will vary in different streets though in a general way it is probable that the purposes are served in the order named. It is possible to install at a low cost a system which will reveal large objects (Purpose No. 1) while failing to serve the two other purposes. With increased appropriations or more efficient illuminants, large objects may be revealed to better advantage and surface irregularities (Purpose No. 2) may also be revealed although the third object may not be served. With still larger appropriations and still more efficient illuminants, discernment may be improved and a pleasing appearance for the street (Purpose No. 3) by day as well as by night may be had. All three objects may be served when appropriations are adequate.

Process of Seeing.—In streets at night objects are seen by reason of contour, relief, shadow or color.

One perceives the contour of objects when they are markedly different in brightness from their background. Since most large objects on the street at night are darker than their background they are usually perceived as silhouettes.

Contrasts in relief are perceived when the exposed surface of an adequately illuminated object presents areas of different reflecting powers, or elements which are more or less favorably inclined with respect to incident light, or elements which lie in the shadow of other elements of the surface.

Small objects may be perceived by reason of their shadows occasioned by the interception of sharply inclined rays of light. Shadows of large objects are not always of value in promoting discernment and are often misleading, as in case of the shadow of a telegraph pole thrown across the sidewalk.

Color contrasts are not usually relied upon since in installations where discernment is at all difficult, color is usually lost and objects are perceived more readily by other means.

The several kinds of contrast perception are suggested in the accompanying series of photographs of test targets. These have been located successively in six representative positions between lamps in the street shown in Figs. 8 and 9. Fig. 1a shows the lighting effects by the centrally mounted lamps shown in Fig. 8. Fig. 1b corresponds with Fig. 9. The targets are of substantially the same color as the street surface. It is to be noted that those which are most clearly revealed receive the least light and are silhouetted against their background. Those least distinctly revealed receive on the observed surfaces about the same light as their background.

Contrast perception is the ruling visual process with which street illumination is concerned. To increase contrasts on surfaces to be seen is to better conditions for vision, a consideration often ignored.

In much of the literature of street illumination, curves of illumination intensity form the principal basis of judgment as to effectiveness. There is a tendency to over-emphasize the importance of incident light to the prejudice of other important considerations. Three of the principal considerations which are not emphasized directly by study of illumination intensity curves are presented in the following paragraphs.

Silhouette Effect.[2]—When the writer directed attention to the

[2] Millar, Preston S., An Unrecognized Aspect of Street Illumination; TRANS. I. E. S., vol. V (1910), page 456.

silhouette effect in 1910, there existed but little appreciation of its importance. During the five years which have intervened there has gradually developed a greater appreciation of the extent to which it enters into conditions of visibility in street illumination. Yet its very general applicability even now is unrecognized by some engineers. There is an impression that only in lighting of very low intensity is it the prevailing method of discernment. As a matter of fact the silhouette effect is pronounced whenever there are bright street or building backgrounds. A photographic under-exposure of any street in the daytime shows objects as silhouettes. The casual glance of an automobile driver corresponds roughly with such an underexposure. The majority of observations of large objects on the street in our more intensely lighted thoroughfares, especially in the practise of automobile drivers, falls under this heading, because a driver is concerned primarily with avoiding obstacles and usually looks carefully enough only to detect the presence of pedestrians and other objects. Usually he sees these as dark objects silhouetted against the lighter street surface or building surfaces. The pedestrian too obtains distant views of large objects as silhouettes. but as he moves more slowly and approaches objects more closely, he has opportunity for closer observation, and in the more brightly lighted streets supplements discernment by silhouette with actual observation of surfaces in relief.

Figs. 6a and 6b show illustrations made from the original silhouette photograph illustrating the importance of this effect in street lighting.

Nature of Street Pavement.—Modern streets which require greatest care in lighting are traversed by automobiles. The majority of them are paved with asphalt, asphalt block, wooden block, treated macadam, etc. As a result of automobile traffic such pavements become oiled and polished. The high spots of the pavement then reflect specularly. Fig. 4 is a night view of a part of Columbus Circle, New York City. The pavement is of wooden block. The street in the immediate foreground of the picture is not traversed by vehicles. The pavement in the outer ring of the circle, which appears in the middle of the photograph, is traversed by vehicles and has become polished in the manner

Fig. 1a.—Test targets in six representative locations as illuminated by centrally mounted lamps as shown in Fig. 8. Illustrating reliance upon contrasts and different kinds of contrasts presented to view.

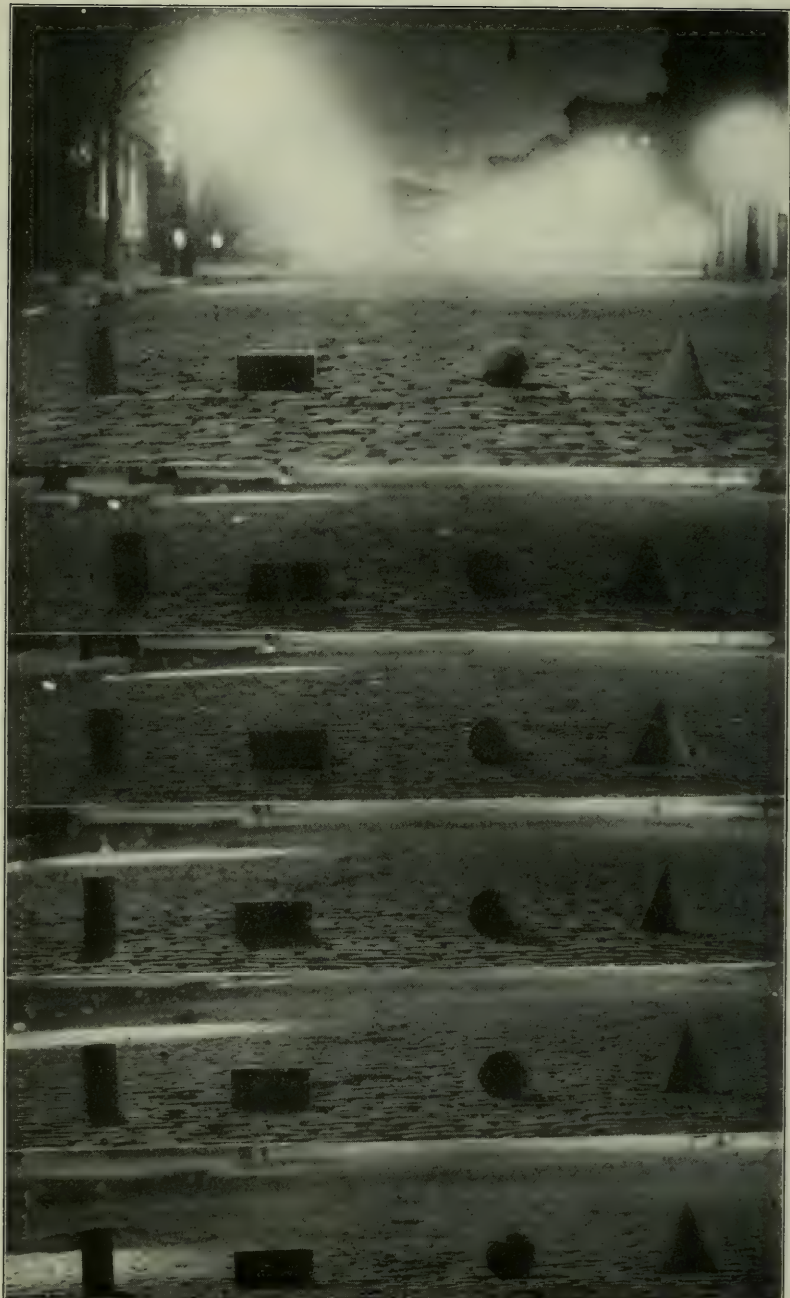


Fig. 1b.—Test targets in six representative locations as illuminated by lamps mounted as shown in Fig. 9. Illustrating reliance upon contrasts and different kinds of contrasts presented to view.

described. It reflects specularly and its brightness as viewed is due largely to distant lamps.

Fig. 2 shows measurements of horizontal illumination intensity and of brightness at the angle of an automobilist's view. The broken line shows horizontal foot-candles as measured on East 80th Street, New York City. This has an ordinary asphalt pavement and is illuminated by multiple enclosed arc lamps 365 ft. (101.15 m.) apart. The continuous line shows brightness values.

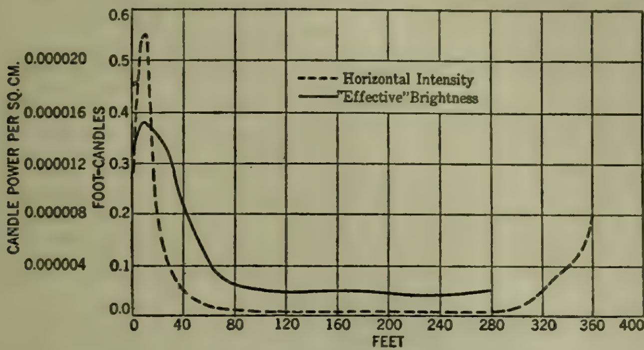


Fig. 2.—Curves of brightness and illumination intensity.

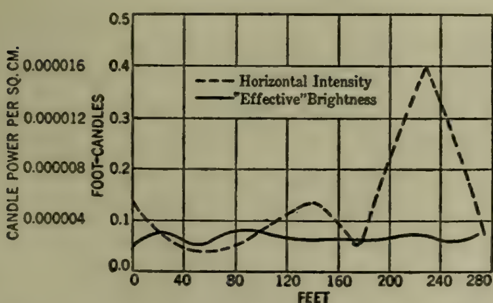


Fig. 3.—Curves of brightness and illumination intensity.

It will be noted that whereas the foot-candles vary in the ratio of 46 to 1, the brightness varies in the ratio of 8 to 1. This is a street in which automobile traffic forms but a small part of the total traffic.

Fig. 3 shows corresponding data for upper Seventh Avenue, New York City, which is a street largely traversed by automobiles. The street is paved with block asphalt. The horizontal

foot-candles vary in the ratio of 10 to 1; the effective brightness varies in the ratio of 2 to 1. The impression of uniformity which one derives from a trip through the street is expressed by this brightness ratio rather than by the foot-candles ratio. On this street, which is of the boulevard, central parkway type, there are three lines of lamps. The linear spacing of the lamps is about 125 ft. (38.1 m.). As the street is fairly level, a great number of these lamps is within view at a given time. The street surface consists largely of small polished areas which reflect specularly In driving through the street one sees reflected in these small polished areas imperfect images or part images of distant lamps. Notwithstanding the rather wide spacing and marked non-uniformity of illumination intensity, the effect is one of remarkable uniformity of lighting. In driving one looks at the street surface 200 ft. (60.56 m.) or more away, and the surface which he sees is rendered bright by lamps which may be one quarter, one half or even one mile away. Consequently the surface between lamps viewed from this angle is almost if not quite as bright as is the surface near or directly under the lamps.

Any street which is largely traversed by automobiles, and which has pavement of the types named above, is likely to appear rather dark because of the oil which is deposited upon it from automobiles. It is, however, a most favorable surface for street lighting purposes because of its tendency to reflect specularly. It was found that Seventh Avenue, New York City, described above, has three to four times the effective brightness per lumen of incident light of another prominent thoroughfare which is paved with Belgium block.

Fig. 11, which will be referred to in another connection, is an additional example of this effect as encountered in a country road paved with treated macadam. Here lamps are spaced 500 to 900 ft. (152.4 to 274.37 m.) apart. The roadway between lamps, from the driver's point of view, is well illuminated; due in part to its specular character.

Recognition of the fact that modern streets are likely to be characterized by more or less of this specular quality necessitates important alterations in some of the theories regarding street

lighting which have prevailed in the past and which are held at the present time by some engineers.

Relation Between Lamps and Street Surface.—The effect of glare in street illumination is dependent primarily upon:

1. The extremes of contrast within view; that is, contrast in brightness between the light source and the illuminated surfaces.
2. The visual angle separating the glaring source from the observed surfaces.
3. The portion of the field of view which is illuminated.

Glare militates against good street illumination, first in decreasing ability to see, and second, in rendering unpleasant the appearance of the installation and the street. Insofar as it reduces visual power it manifests itself in three ways:

First, actual diminutions in ability to perceive small contrasts in the presence of a bright light source. Second, distraction of attention as a result of which small contrasts may not be perceived when viewed casually. Third, a temporary dazzling effect which persists for a few moments after a bright light source is viewed directly.

Figs. 6a and 6b illustrate the effect of glare. In Fig. 6b a black spot covers the nearby light source. In Fig. 6a, the presence of the light source distracts attention from the automobile and the view is rendered less pleasant. In fact there is a little discomfort involved in looking at the automobile. Nevertheless if one deliberately dispells the idea of the glaring source from his mind and concentrates on the automobile, it can be seen in the picture just as well as when the tab covers the light source. This picture further illustrates the importance of securing adequate separation beween the light source and the observed object, the distraction due to the light source being greater relatively when the picture is held at a distance from the eye and the visual angle between the source and object is decreased.

If a single brilliant light source, as a bare gas-filled tungsten lamp is located over a dirt road in the country, the glare is very bad. If the lamp is raised to a greater height or moved to one side of the road, or if the lamp is enclosed in a diffusing globe,

the glare is lessened. If a number of additional lamps are strung beyond it along the road, the glare is further reduced. If the lamps, instead of being located over a dirt road, are located over a treated macadam road, or better still, over an asphalt road, the glare is less serious. Light colored buildings along the street also assist in reducing the glare. In short, anything which reduces the contrast between the light source and the road surface, or which increases the illuminated area within view, or which separates the bright light source from the road surface, reduces the effect of glare.

Sweet in 1910[3] studied that part of the effect of glare which is a measureable reduction in the ability to see, using a single light source in a dark room. He found under these exaggerated conditions that a large reduction in visual power could be traced to the presence of a bright light source close to the center of the field of vision. In 1914[4] working with others on the campus of the University of Wisconsin, he pursued his researches, and has given preliminary publication to some very interesting results. In this latter research he employed from two to four lamps mounted at various heights and with various spacing intervals over a dirt road about 350 ft. (106.68 m.) long, with surroundings of low light-reflecting power. It is not proposed at this time to enter into a discussion of these tests, but it may be noted that the only conclusions which they can indicate are those which would apply to a short stretch of dirt road with surroundings of low light-reflecting power. The modifications introduced by street pavements of better reflecting qualities, by buildings along the street, and by a greater length of illuminated street, have no part in this research. This is a serious limitation, because the effect of glare in street lighting is very largely reduced by each of these three factors. The two researches make available information which has its bearing upon street lighting principles. If, however, the data are considered without due regard to the limitations under which the tests were made, there is danger of forming an exaggerated idea of the importance of adopting measures which will reduce the effect of glare by decreasing the bright-

[3] An Analysis of Illumination Requirements in Street Lighting, *Journal* of Franklin Institute, 1910.

[4] *Electrical Review* and *Western Electrician*, March 6, 1915.

Fig. 4.—View in Columbus Circle, New York City. Note specular reflection from that part of pavement which is traversed by automobiles; also absence of specular reflection from immediate foreground where there is no automobile traffic.

Fig. 5.—Sixteenth street, Washington, D. C., 100-cp. mazda lamps over curbs and dark area in middle of street.

Fig. 6a.—For a demonstration of the importance of separating the glaring source from the observed object hold the picture nearer to or further from the eyes, as the distance from the picture to the eyes becomes greater the visual angle of separation becomes less and the glare effect is magnified.

Fig. 6b.—Original street lighting silhouette picture. Illustrating importance of bright street surface and showing how the automobile is discerned because the street surface beyond it is bright, not because the light falling upon it renders it visible. For a demonstration of glare see Fig. 6a.

Fig. 7.—Magnetite lamps in 28-inch globes as used in Washington, D. C.

Figs. 8 and 9.—Center versus curb mounting in same street.

Fig. 10.—View of country automobile road. Lamp wrongly located on inside of curve. Glare obscures view of road beyond.

Fig. 11.—View of same road shown in Fig. 10. Lamp on side of curve replaced by lamp in the left of view. Change of location enables roadway to be seen. Note specular reflection from roadway due to lamps 600 and 1,000 feet away. Excellent conditions for driving with large illuminants (Magnetite arc lamps with refractors), widely spaced.

ness of light sources to low values. Since the problem is really one of reducing contrast between the light source and the illuminated surfaces, the more constructive way of accomplishing the desired end is to increase the brightness of the illuminated surfaces rather than to dim the light sources unduly. Excessive brightness of light sources must of course be reduced. It is common experience that a simple diffusing globe accomplishes this reasonably well under most conditions. Too great reduction in the brightness of the light source is unsatisfactory psychologically. We like a bright light source—we are dissatisfied with illumination in which a bright light source is not visible. Therefore the thing to do is to eliminate glare by increasing the brightness of the street surface and where desirable that of surroundings, and by reducing the brightness of the light sources moderately throughout the angles at which they are viewed.

With these considerations concerning the importance of the silhouette effect, specular reflection from pavements and glare well in mind, a discussion of the variables of street illumination and of the several factors which the engineer must study in planning a street lighting installation are next in order.

ILLUMINATION VARIABLES.

The effectiveness of street illumination depends upon the following:

(1) Intensity of light upon the street—there is no single measure of intensity which serves all purposes. The average horizontal intensity upon the street surface is most nearly satisfactory. (2) Brightness of street surface—adopting automobilist's viewpoint as to angle and direction. (3) Relation between lamps and street surface—visual angle between the two and extremes of contrast encountered. (4) Contrasts produced on the street surface and on objects on the street—this is largely a function of the direction of the light. (5) Portion of total field of view illuminated—this may be affected either by the number of lighted lamps within view or by the area of surface which is illuminated. (6) Appearance of installation and of street by day and by night—lamps, fixtures, light distribution, etc.

INSTALLATION FACTORS.

Each of the foregoing variables upon which street lighting effectiveness depends is affected by four or more principal installation factors. These are listed in the first column of Table I, in which the variables are given as column headings. The purpose in presenting this table is to emphasize the complexity of the street illumination problem and to indicate the manner in which the several elements are interconnected. Consider, for example, street surface brightness as a variable in street illumination. The table indicates that brightness depends upon the power of the lighting units, the number of lighting units per mile, the kind of lighting accessories employed, the location of lighting units, the nature of the street pavement and the nature of the surroundings. Alteration in any one of these conditions may influence the brightness of the street and therefore the effectiveness of the street illumination. An engineer who considers any one installation condition must appreciate that his decision may be far-reaching in its influence upon the effectiveness of the lighting, since every installation factor influences a number of these variables. Every street presents its own problems, and the utmost effectiveness of street illumination for a given expenditure is had when each factor is applied with due regard to the relations set forth in this table.

TABLE I.—EFFECTIVENESS OF STREET ILLUMINATION.

	Variables					
	Influences through which factors operate					
Installation factors which determine effectiveness	Intensity of light on street	Brightness of street	Relation between lamps and street surface**	Contrasts on street	Portion of field of view illuminated	Appearance of installation and street, day and night
Power of lighting units	*	*	*	*[1]		*
Number of lighting units per mile ..	*	*	*	*	*	*
Kind of accessories	*	*	*	*	*	*
Kind of mount ...						*
Location of lighting units.......	*	*	*	*	*	*
Nature of pavement...........	*	*	*	*		*
Nature of surroundings	*	*	*	*	*	*

** Visual angle and extent of contrast.

[1] Visibility not ratio of reflection coefficients.

TABLE II—LIGHT PRODUCING EFFICIENCIES OF MODERN STREET ILLUMINANT[illegible]

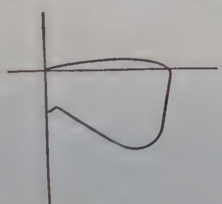
ASSOCIATION OF EDISON ILLUMINATING COMPANIES LAMP COMMITTEE DATA ON [illegible]

(ARC LAMPS SUMMER 1914—MAZDA LAMPS [illegible] 191[illegible])

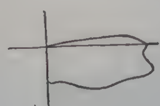
Type	Description of Lamp and Equipment	Mean Initial Values											[illegible]								
		Bare					Equipped for Street Lighting Service						Bare					[illegible]			
		Spherical† candle-power	Total lumens*†	Terminal watts	Watts per candle	Lumens per watt	Spherical† candle-power	Total lumens*†	Terminal watts	Lumens per watt	Watts per candle	Distribution characteristic	Spherical† candle-power	Total lumens**	Terminal watts	Watts per candle	Lumens per watt	[illegible]	[illegible]	[illegible]	[illegible]
Flame arc (various makes of carbons)	G. E. 7.5 10 amp. a. c. compensator, clear globes, white flame electrode	....	....	....	....	....	767	9,638	520	18.5	0.68	Curve A	....	....	....	....	....	[illegible]	[illegible]	[illegible]	[illegible]
	Westg. 7.5 10 amp. a. c. compensator, clear globes, white flame electrode	....	....	....	....	....	681	8,557	480	17.8	0.74	" A	....	....	....	....	....	[illegible]	[illegible]	[illegible]	[illegible]
Magnetite and metallic flame standard type—not the inverted "ornamental" type).	G. E. magnetite 4 amp., standard electrode, clear globe	....	....	....	....	....	238	2,991	310	9.65	1.3	Curve B or C	No material ch[illegible] in cp. throughout [illegible]								
	G. E. magnetite 4 amp., high efficiency electrode, clear globe	....	....	....	....	....	370	4,649	323	14.4	0.87	" B or C									
	G. E. magnetite 5 amp., standard electrode, clear globe	....	....	....	....	....	459	5,768	390	14.8	0.85	" B or C									
	G. E. magnetite 5 amp., high efficiency electrode, clear globe	....	....	....	....	....	609	7,655	371	20.6	0.61	" B or C									
	G. E. magnetite 6.6 amp., standard electrode, clear globe	....	....	....	....	....	693	8,708	511	17.0	0.74	" B or C									
	G. E. magnetite 6.6 amp., high efficiency electrode, clear globe	....	....	....	....	....	937	11,774	509	23.1	0.54	" B or C									
	Westg. metallic flame 4 amp., standard electrode, clear globe	....	....	....	....	....	265	3,330	299	11.1	1.13	Curve D	....	....	....	....	....	[illegible]	[illegible]	[illegible]	[illegible]
	Westg. metallic flame 4 amp., high efficiency electrode, clear globe	....	....	....	....	....	326	4,100	306	13.4	0.94	" D	....	....	....	....	....				
Mazda C	100-watt multiple	93	1,170	100	1.07	11.7	Usual fixtures and containers absorb from 7 to 35 per cent. of the light given by the lamp.					Curve E, F, G or H	84	1,056	98	1.17	10.8	Data insufficient [illegible]			
	200 " "	200	2,513	200	1.00	12.5						" E, F, G or H	180	2,262	196	[illegible]	11.5				
	300 " "	300	3,767	300	1.00	12.5						" E, F, G or H	270	3,393	294	[illegible]	11.5				
	400 " "	400	5,026	400	1.00	12.5						" E, F, G or H	360	4,524	392	[illegible]	11.5				
	500 " "	575	7,225	500	0.87	14.4						" E, F, G or H	518	6,509	490	[illegible]	13.3				
	750 " "	938	11,787	750	0.80	15.7						" E, F, G or H	845	10,618	735	[illegible]	14.4				
	1,000 " "	1,300	16,335	1,000	0.77	16.3						" E, F, G or H	1,170	14,700	980	[illegible]	15.0				
	60-cp. 6.6 amp. series	45.7	574	44.4	0.97	12.9						" E, F, G or H	45.7	574	45.3	0.99	12.7				
	100 " 6.6 " "	80	1,005	73	0.91	13.8						" E, F, G or H	78	980	74.5	[illegible]	13.1				
	250 " 6.6 " "	200	2,513	183	0.91	13.8						" E, F, G or H	196	2,463	187	0.95	13.2				
	400 " 6.6 " "	320	4,021	300	0.94	13.4						" E, F, G or H	314	3,946	300	0.97	12.9				
	600-cp. 20-amp. series compensator	480	6,031	321‡	0.67‡	18.8‡						" E, F, G or H	442	5,554	331‡	0.75‡	16.8‡				
	1,000 " 20 " " "	800	10,053	504‡	0.63‡	19.9‡						" E, F, G or H	720	9,047	520‡	0.72‡	17.4‡				

* Total lumens = scp × 4π
1 lumen (L) = 0.08 scp., approx.

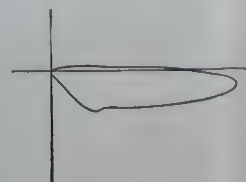
† Variations in average candlepower have been encountered ranging up to 20 per cent. of these values.
‡ Including compensator.



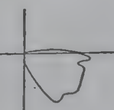
Curve A
Flame arc lamp, clear globes



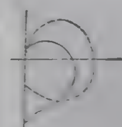
Curve B
Magnetite—reflector and clear globe



Curve C
Magnetite—refractor and clear globe



Curve D
Metallic flame—reflector and clear globe



Curve E
M[illegible] with diffusing globe

TABLE II—LIGHT PRODUCING EFFICIENCIES OF MODERN STREET ILLUMINANTS

EDISON ILLUMINATING COMPANIES LAMP COMMITTEE DATA ON STREET ILLUMINANTS

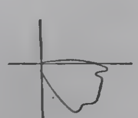
(ARC LAMPS SUMMER 1914—MAZDA LAMPS WINTER 1914)

… Street Lighting Service				Average Throughout Life: Bare					Equipped for Street Lighting Service							Manufacturer's statement
[illegible]	Lumens per watt	Watts per candle	Distribution characteristic	Spherical† candle-power	Total lumens**	Terminal watts	Watts per candle	Lumens per watt	Spherical† candle-power	Total lumens	Terminal watts	Watts per candle	Lumens per watt	Power factor	Approximate life	
[illegible]	18.5	0.68	Curve A	....	....	....	....	....	709	8908	523	0.74	17.0	73%	130 hr. per trim	General Electric Co. approves assignment of values; reports latest lamp with compensator [illegible]. Furnishes following data for latest type without compensator: scp. 890 total lumens 1119[illegible]—watts [illegible] lumens per w. 24. Westinghouse Electric & Manufacturing Company reports for 1915 lamp electrode life of 130 hours and [illegible] compensator, higher efficiency as follows: scp. initial 770—total lumens 9676; throughout life average [illegible] lumens 8,042 terminal watts initial 445, average throughout life, 442; w.p c. initial 0.58, throughout life [illegible] per watt initial 21 7, throughout life, 18.2. National Carbon Company reports for flame arc lamp as a type, 16.9 lumens per watt w.p.c. 0.74 [illegible] with lamp equipped with light diffusing glass-ware.
[illegible]	17.8	0.74	" A	....	....	....	....	....	580	7288	448	0.77	16.3	79%	80 hr. per trim	
[illegible]	[illegible]	1.3	Curve B or C	No material change in cp. throughout trim has been observed.											Data insufficient to permit assignment.	G. E. Co. approves assignment of values. States electrode lives are for two sizes, respectively 230 and [illegible] hr
[illegible]	14.4	0.87	" B or C													G. E. Co. approves assignment of values. States electrode life is 180 hours.
[illegible]	[illegible]	0.85	" B or C													G. E. Co. approves assignment of values. States electrode lives are for two sizes, respectively 15[illegible] and [illegible] hr
[illegible]	[illegible]	0.61	" B or C													G. E. Co. approves assignment of values. States electrode lives are for two sizes, respectively 125 and [illegible] hr
[illegible]	[illegible]	0.74	" B or C													G. E. Co. approves assignment of values. States electrode life is 110 hours.
[illegible]	[illegible]	0.54	" B or C													G. E. Co. approves assignment of values. States electrode life is 75 hours. G. E. Co. states slightly higher candlepower and efficiency obtained in inverted "ornamental" type of lamp.
[illegible]	11.1	1.13	Curve D	....	....	....	....	....	297	3655	310	1.04	11.8	....	317 hr. per trim	Westinghouse Elec. & Mfg. Co. approves assignment of values and claims 250 to 275 hours' life.
[illegible]	13.4	0.94	" D	....	....	....	....	....	....	....	....	....	....	....	....	Westinghouse Elec. & Mfg. Co. approves assignment of values
[illegible] …ature and con- … from 7 to … of the light … the lamp			Curve E, F, G or H	84	1,056	98	1.17	10.8	Data insufficient to permit assignment. See manufacturer's statement.							
			" E, F, G or H	180	2,262	196	1.09	11.5								
			" E, F, G or H	270	3,393	294	1.09	11.5								
			" E, F, G or H	360	4,524	392	1.07	11.5								
			" E, F, G or H	518	6,509	490	0.93	13.3								
			" E, F, G or H	845	10,618	735	0.87	14.4								
			" E, F, G or H	1,170	14,700	980	0.83	15.0								
			" E, F, G or H	45.7	574	45.3	0.99	12.7								
			" E, F, G or H	78	980	74.5	0.96	13.1								
			" E, F, G or H	196	2,463	187	0.95	13 2								
			" E, F, G or H	314	3,946	306	0.97	12.9								
			" E, F, G or H	442	5,554	331‡	0.75‡	16.8‡								
			" E, F, G or H	720	9,047	520‡	0.72‡	17.4‡								

Manufacturer's statement (Mazda lamps):

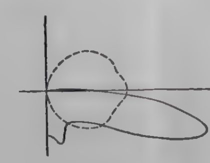
Approximate values for the Summer of 1915: Initial watts per candle	Initial lumens per watt	Approximate average life under correct operating conditions
0.96	13.1	1,000 hours
0.88	14.3	1,000 "
0.82	15.3	1,000 "
0.82	15.3	1,000 "
0.82	15.3	1,000 "
0.76	16.5	1,000 "
0.71	17.7	1,000 "
1.00	12.6	1,000 "
0.91	13.8	1,000 "
0.76	16.5	1,000 "
0.75	16.7	1,000 "
0.63‡	19.9‡	1,000 "
0.61‡	20.6‡	1,000 "

…globe



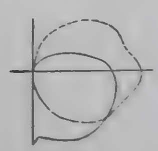
Curve D
Metallic flame—reflector and clear globe

Curve E
Mazda with diffusing globe



Curve F
Mazda with reflector and refractor

Curve G
Mazda—radial wave reflector



Curve H
Mazda with diffusing globe

In attempting to discuss these several elements of the problem it is necessary to generalize, and this in spite of the fact that the great differences in streets of the several classes listed on another page made generalization difficult. Nevertheless it is hoped that a general discussion of the influence of each factor upon the several variables will be of value, particularly since it is proposed to note principally those features in which recent experience has suggested some new consideration.

Size of Lighting Units and Spacing Intervals.—There is now a general tendency toward the adoption of more powerful lamps of one of the three types listed in Table II. These data are available through the courtesy of the Lamp Committee of the Association of Edison Illuminating Companies; in large measure they are authoritative for lamps of the period stated and equipped as indicated.

Of the above illuminants the flame arc lamp and the multiple gas-filled tungsten lamp depreciate in candlepower 20 to 25 per cent. throughout life. The magnetite lamp and the series gas-filled lamps do not change materially throughout life.

Large versus Small Illuminants.—The cluster of lamps employed so largely in "ornamental or white way" lighting during the past five years has yielded in favor in most recent installations to the single illuminant or less frequently to twin illuminants on one post.

The effectiveness of the lighting, other things being equal, is dependent upon the choice as between many small lighting units and few large lighting units. In favor of the small illuminants it is urged that greater uniformity results from their use; that they may be mounted lower, thus avoiding shadows from trees, etc.; and it is added that when small illuminants are mounted low, a larger percentage of their total flux is distributed over the street surface. On the other hand, it is argued in favor of large illuminants that they are relatively less costly per mile, and that usually the appearance of a street lighted by them is more pleasing.

There are two considerations not usually urged in this connection. The first is discussed in more detail under the subject of location of lighting units. Large illuminants are favored

from this viewpoint because they may be placed well out over the middle of the street, where the specular reflection from street surfaces allows the light to be applied in a more favorable direction than that from small illuminants which usually are mounted low over the curb. Fig. 11 is an excellent illustration of the advantageous use of large units in lighting a country road. The lamps are placed 500 to 900 ft. (152.4 to 274.32 m.) apart and 18 to 25 ft. (5.48 to 7.60 m.) high. The effect is good for automobile driving purposes. An example of ineffective use of small illuminants will occur to all who can visualize a wide, wet street with lamps over both curbs. The lighting of the street surface consists of a few bright streaks near the curbs, while the middle of the street is dark. Fig. 5 illustrates this effect upon a dry pavement. As modern street pavements are extended, and automobile traffic increases, the advantages of mounting lamps well over the center of the street tend to increase, and the disadvantages of small illuminants mounted low over the curbs tend to become more apparent.

The second consideration was brought out prominently last year by the Street Lighting Committees of the National Electric Light Association and the Association of Edison Illuminating Companies. It was shown that within reasonable limits, uni-directional light is to be preferred to multi-directional light because it enhances contrasts upon which discernment is dependent. Objects and surface irregularities are seen more surely by uni-directional light than by light coming from a number of directions. From this it follows that, other things being equal, the revealing power of a few large illuminants is greater than that of many small illuminants, especially if the latter are staggered along both curbs.

While these considerations do not clearly indicate the desirability of large units, they do add weight to the arguments in their favor.

LIGHTING ACCESSORIES.

Improved Distribution.—The most desirable distribution of light depends largely on the nature of the street surface and on the character of the street. Hence there is no such thing as a correct distribution characteristic for all street lighting. The

Fig. 12.—Adjustable temporary installation employed in New York City to determine best location for lamps.

Fig. 13.—Carlisle, Pa., 600-cp. mazda C lamps in prismatic refractor units.

Fig. 14.—Fourteenth street, Washington, D. C., 100-cp. mazda C lamps about 10 feet above curb and spaced at intervals of 80 feet along each curb.

Fig. 15.—Lake Avenue, Rochester, 500-watt mazda C lamps, mounted 17½ feet above curb, spaced at average intervals of 225 feet.

Fig. 16.—Main street, Rochester, 6.6-amp. magnetite lamps. Located 14½ feet above curb and spaced at 100 ft. intervals along each curb.

prismatic refractor is successful in providing a distribution characteristic which for a vertical plane conforms to the theoretical requirements as laid down by some engineers. In other forms it will doubtless provide different distributions as required. It is an admirable device so far as re-direction of light is concerned. However, it is objectionable in some forms because of excessive brightness, due to its small size. Also when combined with the casings with which it is usually employed, its appearance is not attractive. Probably in the evolution of this useful device these objections will be overcome.

The same considerations which underlie the design of the refractor, namely the desire to increase the intensities on the street surface at a distance from the lamps, would appear to favor the adoption of asymmetrical horizontal distributions whereby light which normally is delivered upon surfaces lying along the sides of the street is directed upon the street surface. Lighting accessories to accomplish this purpose have been devised, but thus far have not received the extensive trial which their theoretical advantages would appear to warrant.

Diffusing Globes.—The employment of diffusing globes to decrease brightness of light sources in the street has become more general in recent years. Perhaps the extreme example in the way of increased size of such globes is found in the Washington, D. C., installation of ornamental magnetite lamps, in which 23-in. (58.4 cm.) built-up alabaster globes of rather high density are employed. (See Fig. 7.) As compared with the use of a clear globe or of a lamp with no globe, a diffusing globe of fairly large size is usually desirable because it improves the appearance of the lighting unit, renders the appearance of the street more pleasing and promotes good conditions of visibility.

It is desirable to secure the best possible balance between low light absorption and good diffusion when selecting diffusing globes. Test data on these two characteristics are of importance and should not be neglected. Because of neglect of simple and inexpensive tests of commercially available glassware, globes are being installed which do not accomplish the purposes in view so well as would other glassware. These either absorb a larger percentage of light than is necessary to secure the desired degree

of diffusion, or else diffuse less well than need be, considering the amount of absorption.

Protection for the Eyes.—At first glance it would appear that street lighting purposes would be served admirably by a lighting accessory which would concentrate a large proportion of the light flux upon the street surface while directing but little light at those angles which fall near the center of a field of vision in a given installation. However, certain difficulties operate against the success of such a scheme. With practicable mounting heights, spacings have to be short if this is to be successful in illuminating the entire length of the street. The general direction of the light in such an installation is much more largely downward than is usually the case. Wherever there are sufficiently short-interval spacings to allow of such an installation, there usually exists a requirement for lighting the building fronts. In such installations the relatively high intensities on the street surface, together with the large areas of considerable brightness which present themselves to view, render the glare negligible when ordinary diffusing globes are used. That is to say, in the only installations where it is practicable to use such devices, their eccentric distribution characteristics are unnecessary. Where the surroundings are such that the lighting of building fronts is undesirable or unnecessary, spacings are usually too great to admit of the use of such devices, because their illuminating range is too small. Also considerations of street surface characteristics, discussed elsewhere, suggest that suppression of light at say 80° may do more harm by lessening the pavement brightness than can be compensated by decreased brightness of source.

LOCATION OF LIGHTING UNITS.

Comprehended under this heading are such subjects as height, transverse location and spacing. In most city installations these aspects are standardized for a particular street. In lighting of interurban roadways, lamps are sometimes located in accordance with best judgment, varying considerably in all these particulars.

Location Transverse of Street.—As between center and curb locations there is a considerable difference. In the first place with lamps located over each curb, the street appears much wider, as is illustrated by a comparison of Figs. 8 and 9 which are alter-

Fig. 17.—Federal street, Pittsburgh. Series a. c. flame arc lamps, white light carbons. Lamps mounted 24 feet above curb and spaced at average intervals of 69 feet.

Fig. 18.—Fifth Avenue, New York, 400-watt mazda C lamps on twin posts mounted 19 feet above curb and spaced at about 100 foot intervals along both curbs with extra lamps at cross-street intersections.

Fig. 19.—Pennsylvania Avenue, Washington, D. C., 6.6-amp. magnetite lamps as illustrated in Fig. 7. Mounted 15 feet above curb, spaced at 50 ft. intervals along both curbs.

Fig. 20.—Fifth Avenue, Pittsburgh, 6.6-amp. magnetite lamps, mounted 18 feet above the curb, spaced at approximately 80 ft. intervals along each curb.

nate test installations of the N. E. L. A. and A. E. I. C. Street Lighting Committees.

In the lighting of important city streets this is usually a desirable condition. The lamps mounted over the curbs likewise illuminate the sidewalks and the fronts of buildings better. (See Figs. 18 and 19.) When, however, the lighting of the roadway becomes of first importance, as in streets of the 3b class, the best use may be made of the light by locating the lamps as nearly as practicable over the roadway so as to take full advantage of all specular reflection from the street surface. (See Figs. 11 and 5.)

Height.—In regard to height of lamps there is also a wide difference in requirements, depending upon the character of the street. In some of the latest practice, powerful lamps are located 14 to 18 ft. (4.27 to 5.48 m.) over the curbs on business streets. These, however, are backed by light colored buildings and the entire surrounding is so brightly lighted that the glare is not bad. With lamps over the middle of the street the background is usually the dark sky, and usually there are not light colored buildings to relieve the general darkness. Under these conditions the opportunity for glare to become serious is considerable and it is therefore necessary to locate the lamps rather high. The improvement realized in increasing the height of lamps of moderate power from 18 to 20 ft. (5.48 to 6.09 m.) is considerable, while the improvement in increasing the height from say 27 to 30 ft. (8.22 to 9.14 m.) is not very great. The curve of glare falls off rapidly with increasing separation when the separation between the light source and the observed surface is only a few degrees. Around a lamp which has a dark background there is a zone of halation within which objects tend to become invisible. Once outside this zone, the glare effect falls off less rapidly. It is very important to mount the lamps high enough to insure that the separation from the street surface is at least sufficient to avoid this zone of serious glare.

Power of Unit as Related to Glare.—Other things being equal, the objectionable effects of glare are greater when the lighting units are more powerful. Hence it is approved practise to mount the more powerful units higher than less powerful units.

Such a lack of separation is responsible for the serious glare

illustrated in Fig. 10. An arc lamp is located over the inside of a curve in a road obscuring the roadway beyond. The angle of separation between lamp and roadway is about 3°. Fig. 11 shows the same road but with a lamp located over the outside of the curve and separated from the distant roadway by about 20° when viewed as in driving. It must be recognized that a bright light source obscures its immediate background. This obscuration is greater if the light source is brighter or more powerful, and is less if the background is brighter. In country road or park drive lighting such obscuration is often very serious. The illustrations in Figs. 10 and 11 indicate one good way of overcoming this difficulty. Recognizing the truth that under such conditions the bright light sources will obscure a certain region of the field of view, the source is so located that the background which it obscures is one which it is not important to see and that the surface which it is desired to see is sufficiently separated from the glaring light source to avoid difficulty.

Spacing.—All features of an installation should be treated in such a way as to avoid dark areas between lamps, coupled with low mountings for very bright and powerful lamps. To avoid ineffective results due to multi-directional light which reduces contrasts, spacings need to be greater when the lamps are staggered along both curbs than when they form a line along one side or over the middle of the street. The best spacing would appear to be contingent upon the kind of pavement employed and the nature of the surroundings. All the other factors should be so handled that in driving one will not encounter the bad condition of a bright light source preventing an adequate view of the surface of the street beyond it.

Fig. 12 illustrates the very excellent practise which is sometimes followed in the City of New York, in locating lamps for street lighting. Lamps which are temporarily installed may be raised and lowered; those mounted from the mast arm post may be placed nearer to or farther from the curb, and those in the center parkways may be moved about at will, the posts being mounted in rock-ballasted barrels. A crew of men locate the lamps in the trial installation as directed by the engineers in charge and the locations which appear to give the best illumi-

nating effects are arrived at. Photometric tests are then made to show the results obtained and to afford a basis for the planning of other installations.

THEORETICAL CONSIDERATIONS WHICH HAVE NOT BEEN DEMONSTRATED.

Color.—In street illumination where intensities are low, it is believed by some engineers that white light is more effective than yellow light. According to this view, objects are revealed with greater definition; smaller contrasts may be perceived, and there is less suggestion of haziness in the atmosphere when white light is employed. In accordance with the Purkinje effect there would appear to be some basis for this theory, since it is well known that in intensities of the order of 0.01 foot-candle, we see almost exclusively by red vision and the maximum of the ocular luminosity curve is removed toward the blue end of the spectrum. Whether or not this effect is present in street lighting is one of the interesting subjects of speculation at the present time.

Whether or not white light possesses advantage for low intensity street lighting due to ocular peculiarities, it is certain that it is preferred by many for high-class street lighting on the ground that it is more suitable, pleasing and dignified than is yellow light. This is perhaps a matter of color association, and is surely a matter of taste. It, therefore, hardly finds place in a discussion of this kind, and is merely mentioned in passing.

"Animation" of Light Source.—It has been suggested that the slight fluctuation of light which characterizes arc lamps possesses some advantage for street lighting purposes over the steady glow of the incandescent lamp. So far as the writer knows, no demonstrations have been undertaken, and it has not been shown that this speculation has any basis in fact.

GENERAL STATUS OF THE PROBLEM OF STREET ILLUMINATION.

There is an important consideration suggested in the first paragraph of this paper. As more money is expended on street lighting and as more efficient lamps are made available, the intensities of light in streets become greater. As the intensities increase, the requirements for the best possible application of light to promote

good visibility conditions become less severe and the requirements for application which improve the appearance of the street become more urgent. From the standpoint of rendering visible the street and objects upon it, the lighting of suburban automobile roads where but little money is available for installation and operation offers the best test for the engineer's skill. In first-class streets we have already progressed to the point where esthetics assume large importance. This does not mean, however, that the problems of street lighting are becoming less difficult; it means simply that the problems are becoming more involved, and broader comprehension of the fundamental principles of street illumination is becoming more essential.

Appendix.—In the appendix will be found some statistics of very recent installations in streets of several classes showing practise in this country as of the early part of 1915. These are accompanied by a few photographs.

Acknowledgment.—The author wishes to express his indebtedness to a number of gentlemen who have kindly supplied some of the photographs and statistics which are utilized in this paper, and who are too numerous to permit of individual mention in this connection.

DISCUSSION.

MR. G. H. STICKNEY: There is more difference of opinion as to what is the best practise in street lighting than in any other class of lighting problems. This is due in part to the efforts to classify a wide variety of demands into one or two groups of practise, at the same time putting the extreme emphasis on the cost. Since the disagreement originates with the ultimate lighting effects, the lack of agreement as to the methods of producing such effects is not surprising.

The careful analysis presented in Mr. Millar's paper, while not furnishing a solution of the problems, is an important aid in that direction, through clearly defining some of the fundamental facts which have not been generally recognized.

One of the most important divergences in practise is that between the large and small, or the high power and low power lighting units. There seems to be little doubt but that the larger

units are generally better for high intensity lighting, and the smaller units more economical for low intensity lighting. The majority of our street lighting problems, however, fall in a class of intermediate intensities, where there is considerable question as to which size of unit will give the best effect for the least cost. Good lighting can be produced from either. The latest tendency seems to be to follow the logical practise of applying units of intermediate power.

We often note the tendency to measure the value of street lighting units in terms of their efficiencies. Although, all else being equal, this would be a fair measure, practically, there are other considerations, such as, maintenance cost, adaptability, convenience, appearance, steadiness, etc., which often outweigh a considerable difference in efficiency. This has been illustrated in the transition from the open arc to the enclosed arc, and also in the remarkable spread in the incandescent cluster light, which despite its notorious inefficiency enjoyed an almost unprecedented popularity. This cluster lighting was never viewed with high favor by engineers, and while it is now giving way to more economical and artistic single light posts its former popularity should be recorded as the vote of the public in favor of more ornamental street lighting.

Referring again to the efficiency question, it must be remembered that to-day the item of electric energy consumed represents only about 20 to 25 per cent. of the cost of street lighting service, so that even large gains in efficiency represent relatively small savings. Such gains can, therefore, usually be more profitably taken up in raising the standard of lighting.

The practise of oiling the road and street surface has had a very important relation to street lighting practise. Due to the blackening of the surface, streets which were formerly quite satisfactorily lighted become dull and dingy looking. While the glint effect of such streets is valuable to the automobilist in discerning objects, the black surface absorbs so much light that it is very difficult to produce a pleasing and cheerful lighting effect and much more light is required than in the case of light colored pavements such as asphalt. It can hardly be expected that the color of pavements will always be selected to facilitate street

lighting, but there are many cases in which it would be desirable to consider the street lighting in this connection.

PROF. DUGALD C. JACKSON: This paper is, I hope, a forerunner of other papers to be given at joint meetings of the two societies which are here to-night. Papers of a similar nature have been given by Mr. Millar and other authors before the meetings of the Illuminating Engineering Society, but these papers have not been given the general attention of electrical engineers that the subject warrants.

There are certain features of this paper which impressed me very much and of which I will speak. To begin, the paper refers to the change of attitude of engineers who have to do with street lighting, which has turned them from the enclosed series arc lamp to other types of lamps, and for myself I want to express very great satisfaction in that. I have always believed that the enclosed series arc lamp (especially when operated on alternating current) was one of the mistakes of electrical engineers, and that it arose by allowing the question of the cost of maintenance of a particular machine or piece of apparatus to take the place of consideration of the real effectiveness of its service. Fortunately, electrical engineers and others are now turning their attention to more satisfactory illuminants, *i. e.*, more satisfactory when judged broadly, and not solely from the standpoint of how many hours a particular lamp may be burned, or how much labor may be requisite to maintain the structure.

On the other hand, I believe we are likely to be misled by the charm of simplicity in the mazda lamp and perhaps go too far in utilizing the slightly yellowish light for illuminating important streets. Certainly in the great streets of our cities most individuals are more pleased with the white light than with the yellowish light. There is no question about the possibility of lighting streets and roads with mazda lamps of large candle-power very satisfactorily, but a white light is to more of us more satisfactory, more enspiriting, which is a feature of real importance in a city street in the major business district. The yellowish light, however, probably serves the purpose with full satisfaction in the residence and also perhaps in less occupied business streets.

In my opinion, the question of large versus small units will

work itself out. I am convinced, that the large units are bound to be used for the important streets of a city. The American cities must, like the foreign cities, become convinced that they need floods of illumination in the regions of great mercantile activity, although they do not need so much light elsewhere. To secure real flood illumination, large lamp units must be used.

There are few objects more graceful and beautiful than a pair of fine white lights on a graceful post, when these lights are properly protected by a fairly large white diffusing globe—the globe being large enough so that any spot in the tremendous amount of light that may be given off may not have any serious effect on the eye. On the other hand, there are cases where sincere effort has been made to get rid of glare according to the mistaken ideas of some man who put up the system, in which rows of large intense lights, with diffusing globes, placed 22 or 24 ft. (6.70 or 7.31 m.) high, 150 to 250 ft. (45.72 or 76.20 m.) apart, down miles of road make a nightmare to travelers on account of the physiological effect of the continuous rows of illuminants on each side, which affect the eye with great discomfort.

One of the most pleasing results of the recent work of illuminating engineers in this country is the attention which is being turned towards the use of graceful lamp posts in the cities. I here avoid the use of the words "decorative posts," because the phrase "decorative lighting" has covered such a multitude of sins by way of ugliness during the last few years. Graceful posts are coming into style. The old mounting of an arc lamp, or some other lamp, on a strip of iron, fastened by a lag screw to a crooked wooden pole, which otherwise carried crossarms and wires, was a poor sort of expedient for supporting the street lamps, but if our cities can recognize the worth of, and spend the money necessary to secure graceful posts, I am sure that they will be improved and made happier as places for living.

Mr. Walter R. Moulton: Referring to the discerning of surface irregularities in streets, I have in mind one interesting example in Baltimore where a water-front street about 100 ft. wide is paved with Belgian block and is lighted by means of luminous magnetite arcs on standards located on safety islands down the center of the street. The rough spots in the street are

brought out very distinctly by the shadows cast and also by the increased intensity of illumination on the face presented to the source of light. Because of the nature of the paving, one would hardly expect to find surface reflection, but objects do stand out in silhouette as the granite blocks are worn quite smooth and there seems to be reflection from each individual block. The conditions of the street also illustrate very forcibly the advantage of illuminants on one side of the roadway only as this condition is quite analagous to such a road.

The effect of street paving on the illumination of a street was very plainly shown when the paving on both Howard and Eutaw Streets in Baltimore was changed from Belgian block to sheet asphalt. The location of luminous arc lamps was not changed, but after the completion of the asphalt paving the lighting condition of the street seemed to be greatly improved. Another interesting effect of street surface is found on the Fallsway, which is a new concrete structure. The entire surface of the road, the sidewalks and a 3 ft. wall on either side are of concrete and lighted by means of luminous magnetite arc lamps similar to the downtown business streets. This roadway has been in use about nine months and at the present time has absolutely no specular reflection from its surface. The surface of the street, however, seems very well illuminated and the diffuse reflection from the light colored surface seems to replace specular reflection very well in improving the apparent illumination of a street.

Specular reflection from the surface illumination is important in other outdoor lighting than street illumination. There is a large municipal bathing pool in Baltimore, covering over two acres, which is used at night as well as in the daytime. A number of incandescent lamp standards are located around the pool and also on platforms and pedestals in the center of the pool itself. The general illumination is very good, but ability to see objects on the surface of the water is entirely due to the specular reflection of the lights on the surface.

The excessive brightness of a prismatic refractor unit combined with a high candlepower lamp is forcibly illustrated by the difficulty experienced in attempting to photograph such installations. Would this not indicate that such units are brilliant enough to

interfere considerably with vision and would it not also seem to point out that their size should be increased?

The commercial value of lavish application of street lighting in the downtown section is well illustrated in Baltimore where over 1000 luminous magnetite arc "white-way" lamps have been installed. At night the business section of the city is made very prominent, it shows up quite strongly from the hilly sections surrounding the city and especially so from the bay. The illumination in the sky from a distance is quite strong and the tall buildings stand out quite prominently against the sky as the entire face of the building is illuminated.

This latter feature of lighting the building fronts is one that should not be overlooked. The civic buildings, namely the Court House, Post-office and City Hall are located on three consecutive blocks with wide streets on either side and a plaza on each end and between the buildings. There are several well designed office buildings facing the civic buildings. The generous use of white-way lamps in this section makes these buildings quite prominent, especially as they are of light colored stone, the Court House being of white marble. This section is made really more attractive at night than it is in the daytime.

The esthetic effect of lighting standards or posts throughout the city is quite important. If possible one typical design should be carried out. In Baltimore a special design standard was developed for use with the luminous arc white-way lamps. This same design has since been carried into the residence sections for use with the incandescent lamps and round globes and it has also been carried into the parks. There are a great number of bridges in and around the city and this same design standard has been scaled down and is to be found along the side wall of bridges. Thus there is a harmonious effect produced that is very pleasing. A contrast, however, has been made in Roland Park, an exclusive suburban section, where a special design corner post has been developed, supporting a rustic lantern and also supporting name plates for each street.

The beauty spots of a city can be made prominent and their artistic value greatly enhanced by good street lighting. This is especially true of the small squares and parks to be found in any

large city. The bright street lighting surrounding the small park serves as a background against which the dark foliage of the trees shows up very strongly in silhouette. Often a dainty lace-like effect is obtained. The lights in the small park itself serve very well to bring out the beauty of well-formed trees or banks of shrubbery. The variations of light and shade are such as to make the park of untiring interest.

MR. H. H. MAGDSICK: Mr. Millar has shown clearly what factors determine the effectiveness of the illumination in streets with characteristics typical of our main thoroughfares. For such streets, where the requirements of the driver of a vehicle form the major consideration, the importance of these factors can scarcely be over emphasized. The discussion would not appear to apply with equal force to most residence districts, which contain a large proportion of the total mileage of streets we have to light, where the safety and convenience of the pedestrian are primary. In serving these the incident light is of far greater importance than in the other class of streets and the silhouette effect, specular reflection from street surface, etc., are of lesser value. With the funds now available for street lighting in some cities a sufficiently high intensity can be provided at all points on the street to meet these requirements satisfactorily when modern equipment is employed.

It is pointed out in the paper that a bright light source interferes with vision most when the angle of separation between the light source and the surface viewed is small. This effect is to some extent decreased by mounting the unit at a greater height; but considerations of cost, inefficiency and possible obstruction of light, limit this method. It is not generally recognized that much the same result can be secured by the use of prismatic refractor equipment so installed as to direct the maximum candle-power at an angle of, say, 70° from the vertical, with a considerably reduced intensity at the higher angles, which are viewed when the angle of separation from the illuminated surface is small. The use of this equipment likewise increases the brightness of the street surface. A sufficient intensity is still emitted at the higher angles to satisfy the desire for some brightness in the illuminant and to aid vision when specularly reflected; how-

ever, it should be borne in mind that only certain classes of street

City and Street	Descriptio			
	Width of roadway in feet	K	Accessories	Building fronts lighted?
Pittsburgh, Pa. Fifth Avenue .	36	Bu	Medium alabaster globes	Yes
Pittsburgh, Pa. Federal Street . .	47	Bu	Alba globes	
Chicago, Illinois Dearborn Street .	42	Bu	Alba globes	Yes
Rochester, N. Y. Main Street . . .	80	Bu	Alabaster globes	
Hartford, Conn. Main Street . . .	90 ft. bet bldg. lines		Novulux, Form 1.	
Washington, D. C. Pennsylvania, Av.	109	Al	23-inch segmented Alabaster globe —dense upper, medium lower hemisphere	Well
New York, N. Y. Fifth Avenue. (25 to 58 Sts.) . .	60	Bu	Light Carrara globes	Yes
Corning, N. Y. Market Street		Bu	C. R. I. globe and translucent glass reflectors	
Rochester, N. Y. Lake Avenue . .	50	Re	Alabaster globes	
Milwaukee, Wis. Grand Avenue . .	92	Bu	Light alabaster globes	Yes
New York, N. Y. Seventh Ave. (110 to 136 Sts.)	80	A	Special ventilated unit—light Carrara globe	
Chicago, Illinois Troy Street . . .	36	R	Alba globes	No
Washington, D. C. Sixteenth Street .	50 ft. (160 ft. bet bldg. lines).	R	16-inch Alba globes	

light sources are still visible, although in many cases the intrinsic brilliancy is reduced by diffusing globes. Nevertheless, the lamps are conspicuous, and I have yet to see a globe which does

City and Street	Description of Street		Installation							
	Width of roadway in feet	Kind of buildings	No. of lighting units	Linear spacing if feet along one curb	Height in feet	Location	Kind of mount	Lamps	Accessories	Building fronts lighted?
Pittsburgh, Pa. Fifth Avenue .	36	Business structures	50	Approx. 80	18	Both curbs—opposite	Brackets on trolley poles	6.6-amp. d-c. ornamental luminous arc	Medium alabaster globes	Yes
Pittsburgh, Pa. Federal Street . .	47	Business structures	90	69	24	Both curbs—staggered	Ornamental posts	a-c. series flame arc white electrodes	Alba globes	
Chicago, Illinois Dearborn Street .	42	Business structures	102	94	25	Both curbs—staggered	Ornamental posts	a-c. series flame arc lamps	Alba globes	Yes
Rochester, N. Y. Main Street . . .	80	Business structures	222	100	14 ft. 6 in.	Both curbs—opposite, main section—staggered outside.	Ornamental posts	6.6-amp. inverted magnetite	Alabaster globes	
Hartford, Conn. Main Street . . .	90 ft. bet bldg. lines		Approx. 82 (twin lamp)	112	14	Both curbs—staggered	Twin lamp ornamental posts	600-cp. mazda C.	Novulux, Form 1.	
Washington, D. C. Pennsylvania, Av.	109	All kinds	123	100	15	Both curbs—staggered	Ornamental posts	6.6-amp. inverted magnetite—stand. elect.	23-inch segmented Alabaster globe —dense upper, medium lower hemisphere	Well
New York, N. Y. Fifth Avenue. (25 to 58 Sts.) . .	60	Business structures	200 (2 per post)	100	19	Both curbs—staggered	Twin lamp ornamental posts	120-volt, 400-watt multiple mazda C.	Light Carrara globes	Yes
Corning, N. Y. Market Street		Business structures		100	13 ft. 6 in.	Both curbs—opposite	Ornamental posts	400-cp., 15-amp. mazda C.	C. R. I. globe and translucent glass reflectors	
Rochester, N. Y. Lake Avenue . .	50	Residences	56	400	17 ft. 6 in.	Both curbs—staggered	Ornamental posts	1000-cp. mazda C.	Alabaster globes	
Milwaukee, Wis. Grand Avenue . .	92	Business structures		92	19 ft. 10 in.	Both curbs—opposite	Bracket on trolley pole	4.0-amp. d-c. series ornamental luminous arc—long life electrodes	Light alabaster globes	Yes
New York, N. Y. Seventh Ave. (110 to 136 Sts.)	80	Apartment buildings	79	105	22	In center of block (on center isle) On curb of intersecting streets at house line of cross street intersection	Ornamental posts	120-volt, 400-watt multiple mazda C.	Special ventilated unit—light Carrara globe	
Chicago, Illinois Troy Street . . .	36	Residences		220	22	East curb only	Ornamental posts	600-cp. mazda C.	Alba globes	No
Washington, D. C. Sixteenth Street .	50 ft. (160 ft. bet bldg. lines).	Residences	246	120	10 ft. 3 in.	Both curbs—staggered		5.5-amp. series mazda C. approx. 75 watts	16-inch Alba globes	

ever, it should be borne in mind that only certain classes of street surfaces reflect specularly to any considerable extent. A study of the streets in many large and small cities has shown that this is a negligible factor in the illumination of a large proportion of the total.

In Table II the average life of series mazda C lamps under correct operating conditions is given as 1000 hours. It may be noted that while the manufacturers have made guarantees on this basis to cover a large range of street lighting circuits and operating conditions, the actual performance in service as reported in the technical press and at a convention of electrical associations shows that the manufacturers' rated life of 1350 is conservative.

Mr. W. H. Pratt: There is an observation which I have made, and which has rather been thrust upon me in reference to street lighting, which I would like to offer for what it is worth. There is a strip of boulevard, some four or five miles long, over which I frequently drive in the evening, and it is illuminated so that it works satisfactorily, so far as the visibility of objects on the road are concerned. The sources of illumination are moderate sized units, spaced very regularly. I find that when somewhat tired, especially when driving over this road, there is a very painful effect due apparently to the very regular passage of sources of light before the eyes. I wonder if this might not be a factor at times to be considered in determining whether large or small units shall be used. The effect is very noticeable and sometimes is really extremely painful. I can easily understand how under the circumstances a driver might be led to make serious mistakes from that cause. It has a somewhat hypnotic effect, definitely associated with the very regular passage at rather frequent intervals of the light sources through the field of vision.

Dr. John B. Whitehead: We have been shown in very convincing and beautiful fashion the importance of specular reflection and the value of a highly reflecting surface in streets and roadways. I notice in all the pictures and in the model that the light sources are still visible, although in many cases the intrinsic brilliancy is reduced by diffusing globes. Nevertheless, the lamps are conspicuous, and I have yet to see a globe which does

not in some measure give the disagreeable impressions generally associated with glare. I remember also that when Mr. Millar showed us a lantern slide in which an attempt was made to illuminate a road with concealed sources, the slide indicated that the result was an extremely poor one and not to be compared with that which had been obtained by these methods which he endorses. The question arises, as to whether the distribution curves of various reflectors which conceal the source completely have been studied in their relation to the angle of incidence of the light upon the road surface. In other words, would it not be possible to get a considerable amount of scattered reflection at high angles of incidence?

MR. PETER JUNKERSFELD: Most of our discussion this evening has been on the illumination of streets, largely from the viewpoint of the pedestrian on the street, or the people using automobiles on the street, or the general illumination of the street. There is one other party whose interest should be considered, and that is the resident along the street, and particularly the resident whose home is opposite some of these high candlepower lamps. I have in mind an installation of 3,000 or 4,000, 600-candlepower type C mazda lamps in Chicago, installed under the direction of Mr. Ray Palmer. That system of lamps was installed on tubular iron poles, using tubular iron poles also between the poles supporting the arc lamps, and the lighting is very satisfactory from the standpoint of street illumination. A great many complaints, however, have arisen from residents on the street. These high candlepower lamps shine into the second and third story windows, particularly in the summer time, when people do not want their shades down, but want them part way up, so that they can get as much air as possible, and it is quite objectionable from their standpoint. Many complaints have come in and in some places the residences along the street have taken matters into their own hands and painted the sides of the globes. It finally resulted in the passage of an ordinance under which any resident along the street may have a special shade put on the lamp by paying $2 per lamp and $1 per year in advance for the maintenance of the shade. It probably is not sufficient to cover the cost, but serves as a deterrent against unnecessary shading. The lamps are mounted on poles, 25 ft. (7.62 m.) above the surface of the street.

In other sections of the city where wires are put under ground by common consent the small unit lamps on low poles, 10 or 12 ft. (3.04 or 3.65 m.) high, have been installed, and that system, from the point of view of the residents, is very much more satisfactory and at the same time gives very good street illumination.

I would add a word to what Mr. Stickney said and possibly also to what Prof. Jackson said, and that is, after all, this whole matter of street lighting must be a matter of compromise. There are many other things which are to be considered besides illumination. The staggering of lamps improves the illumination in many cases. That means, however, considerable increase in cost in installation, whether the wires are overhead or underground, because the wires must cross back and forth across the street, or else there will have to be two lines of poles. There are a great many other factors of that kind that must be taken into consideration in every individual system.

Mr. Allen T. Baldwin: In the author's paper, in the paragraph entitled "Power of Lighting Units," reference is made to the depreciation in candlepower of the flame arc and multiple mazda lamps. A depreciation of 20 to 25 per cent. is claimed for each unit mentioned. Insofar as the enclosed type of flame arc lamp is concerned, we have found at our laboratories that 15 to 20 per cent. is the average depreciation when measured as the part of the total light flux that is lost through absorption by dirty glassware. For white flame carbons the lower value is nearer the true average.

The light absorption arises from two causes: the etching of the globe and the adherence to the globe of deposits from the arc. The loss of light as the result of etching is the smaller loss of the two. It will probably not exceed 5 to 10 per cent., and a test recently completed on a globe that had been in service over 700 hours showed that it was capable of transmitting 96 per cent. of the light transmitted by such globes. The test was made in such a way that this loss was that known to be due to etching alone. Studies have shown that the etching and deposits are least in that part of the globe where it is desirable to have the best light transmission. At the end of the trim life the loss at 80° from the vertical is approximately 5 per cent., while at 10° from the vertical the loss approaches 40 per cent. or more.

A comparison of the distribution curves of the lamp at the beginning and end of the life will show that the distribution has been changed in a beneficial way. The deposit in the bottom of the globe acts as a reflecting surface and extends the values along the horizontal at the expense of the light directly along the vertical. These facts point out that the candlepower depreciation is best determined as the loss of total light flux rather than that in any given direction. In reality the increase in efficiency of the lamps gained by eliminating globe etching and deposit would hardly be enough to warrant more than passing attention.

In connection with this subject it is interesting to note that it seems to be an inherent tendency of white flame carbons to give an increase in candlepower as they are consumed, but not to a sufficient extent to counteract the losses just referred to.

MR. L. D. NORDSTRUM : The point Mr. Jackson brought up in regard to the difference in illumination which might come about when different types of lamps were used, I have had brought to my attention several times in the fact that we have two different installations in Fort Wayne, practically a duplicate form of installation outside of the light sources used. The old lighting system used the usual type of single unit placed on street corners, usually in the center of the street. Some two miles of the main streets were changed over to what we called ornamental lighting. The poles were placed on the curbs on each side of the street and staggered. They carried a double crossarm with a lamp on each end and a fifth lamp in the center of the pole with 100-watt mazda lamps in each globe. This had been installed about a year, and then for about the same distance a new form of lighting was carried out, the same method of pole installation, and poles about the same height, in which we used 4-ampere magnetite lamps. I think that everybody is agreed that the magnetite installation gives much better illumination. Something like seven or eight months ago we had in the evening a very dense fog. These two installations happen to be along the same street, so that they could be compared, and in this dense fog the light from the mazda lamps seemed to be entirely blotted out. One could see the mazda lamps about a block away. Going down that portion of the street having the magnetite installation one could see

the magnetite lamps strung out along the street a fairly good distance away, for several blocks, at least; whereas with the partially yellow light from the mazda lamps the illumination was not nearly so effective.

MR. J. D. MORTIMER (By letter): Skill in the design and application of equipment for the illumination of streets has not progressed as rapidly as has the design of illumination for building interiors. Attention to this branch of engineering has been spasmodic. With the many interests involved, the practical design of a system of street lighting requires many more compromises between scientific principles, politics and finances than usually occur in other engineering undertakings. Where the relative importance of the different factors measuring the effectiveness of street illumination is still in dispute, it is not surprising that every engineer possessed of a street lighting client, differs from all other engineers. It is hoped that Mr. Millar's analysis will materially assist in reconciling the less important differences and concentrate future discussion on the remaining few but important factors.

Efficiency and size of lighting equipment, character of distribution of illumination, intensity, street surfaces, glare, spacing, mounting height and appearance, are all of importance in the design of a street lighting system. They all have some bearing on the ideal scheme. No design can be said to be completed until it is known what the annual costs of operation will be. Assuming that the ideal plan can be laid down, the question arises, are the improvements worth the cost? The increment cost of small improvements in illumination should not exceed their value. Value depends upon time, place and the state of public opinion.

There will be fashions in street lighting as there are in architecture, street cars, politics, and hats. Fashion alone will condemn as obsolete any system installed to-day long before it has served its mechanically useful life. This fact has a bearing on extent to which effective illuminating value may be created by additional costs. The costs may be added for a period of several years and the value rapidly depreciate after its novelty has worn off. The financial factor in a subject as commercial as street lighting, is yet one of the most important, and no study can be

said to approach completeness that does not incorporate the monetary aspects as an essential part.

MR. F. C. PIATT (By letter): Mr. Millar calls attention to three means by which street lighting can be improved, (1) larger municipal appropriations; (2) more efficient lamps and accessories; (3) greater skill in application. To this list I would add a fourth item which is extremely important, even more so than the obtaining of more efficient lamps: this is to procure lamps and accessories having a lower first cost and lower cost of operation.

For the ordinary magnetite or carbon arc or large size type C mazda lamp the cost of energy amounts to about 25 per cent. of the total cost of service (including interest, depreciation, etc.) while the fixed charges and operating expenses comprise the remaining 75 per cent. Hence it is evident that if a 10 per cent. reduction in first cost and operating expense can be made, the total cost will be lowered as much as by a 30 per cent. improvement in efficiency.

The mazda series lamp has made rapid progress in spite of the existence of the magnetite arc largely because the cost of the lamp and reflector is much lower than the arc lamp. Also the constant current transformer is much cheaper than the magnetite rectifier.

In regard to the question of large versus small illuminants, it may be of interest to see exactly what the effect is from a cost standpoint if the size of the units is varied. The only system in which the size of units can be practically varied is that using mazda series lamps, as with the arc lamps the only variation is from large to larger candlepower, no small units being available.

The most valid argument against wide spacing of lamps is the practical necessity where blocks are short of locating a lamp at least at every street intersection to serve as a marker as well as to supply some illumination along every road traversed. Crooked, and tree lined roads also call for closer spacing and smaller units.

In Mr. Millar's paper considerable attention is given to the question of lighting for motorists particularly on suburban roads. I do not see that the motorist should be given much consideration except to so place the street lamps as to avoid serious glare, and to insure that road intersections are well marked. The headlights

of a motor car are much better for showing road irregularities than any lighting system could possibly be, due to the shadows obtained from the lights close to the ground.

The principal object in lighting suburban roads to my mind is to insure safety to the pedestrian or other traveler without light. This also applies largely to the lighting of city streets, where the more pleasing effect and better conditions for pedestrians secured by curb lighting seem more important than the lack of specular reflection which might aid the motorist.

Mr. Preston S. Millar (In reply): Prof. Jackson has emphasized the possibilities of further intensive study and development in the illumination field. His point appears to be well taken. Those who have visited the Exposition at San Francisco have derived a great deal of inspiration in this connection.

Replying to the question regarding the measurement of effective brightness, it should be stated that the measurements were made about five years ago and were rather crude. After a few trials, we determined the usual angle of an automobilist's view of the street surface, arriving, if my recollection is correct, at 2° as a typical angle. With a photometer we then measured the brightness of arbitrarily selected patches of street surface at such angle.

Due to the great increase in automobile traffic during these past five years and to the more general adoption of modern pavements, the departure of the brightness curve from the curve of incident light is probably now greater than was found to be typical five years ago.

Mr. Moulton has shown that the prismatic refractors employed in Baltimore are so bright as to spoil the photographic effect by reason of excessive halations. It would appear to be proper to ask if these refractors are not also so bright as to spoil the illuminating effect. In one of the views which he has shown there is an illustration of the lighting of a public building by magnetite lamps along the curb. It is to be observed that the lower stories of the building were lighted nicely, but the upper stories were not well lighted. If these lamps could be moved across the street from the building, securing a greater distance and a better angle of incident light, the general lighting of the front of the building would probably be better.

Mr. Magdsick has dwelt upon the point of view of the pedestrian as opposed to that of the automobilist. I am not sure that these viewpoints are essentially different. In the proposed lighting of a Cleveland street which he has described, I think we arrive at that class referred to in the paper in which esthetic considerations are of first importance. In such problems most of the questions discussed in the paper are of relatively less importance because there is so much light available that application to secure the best visibility is unnecessary.

Dr. Whitehead has suggested that it might be possible to obtain the advantages which come with specular reflection from street surface and still avoid all glare effect. I think he will find that in cases where we have to take advantage of specular reflection the spacings are so great that light must be allowed to emanate from the lamp at such a high angle that it will produce some glare. When the spacing is so short that the glare effect can be suppressed, there is so much light that ordinary exposure of lamps in diffusing glassware does not produce much glare. The work of Mr. A. J. Sweet may be consulted with profit in this connection.

Mr. Junkersfeld's citation of objection on the part of residents to light on the uoper stories of houses is mentioned in the paper as well.

Mr. Baldwin implies that the depreciation during life shown for flame arc lamps is a bit too high. We have received criticisms from others that it is a trifle too low. If we may be permitted to average these criticisms, we will conclude that the figures shown in the paper are probably substantially typical.

Mr. Mortimer's discussion emphasizes the monetary aspects of street lighting as fundamentally important. To this no exception can be taken. They are of transcending importance. He states that the increment cost of small improvements in illumination should not exceed their value. "Value depends upon time, place and state of public opinion." I like to think that it is appraisal rather than value that depends upon time, place and state of public opinion. For the value of an improvement it seems to me is measured in the added effectiveness of the lighting. Again, I like to think that it is the opinion of public representatives rather

than public opinion which determines the appraisal. Discussions of this kind should promote ultimate consensus regarding effectiveness and should hasten the time when appraisal of street lighting values by public representatives and public utility representatives will be in agreement.

Mr. Piatt deprecates the consideration given in the paper to the requirements of automobilists, stating that headlights furnish the best lighting for his purposes and that therefore street lighting in suburban roads should be designed principally for the purposes of pedestrians. Within the city limits of some large cities the employment of headlights is not permitted. It is preferable to avoid the use of headlights in much traveled streets, and it is entirely practicable to do so if the street lighting is reasonably effective. Investigation has shown that large differences in the effectiveness of street lighting do not interfere seriously with the progress or safety of the pedestrian. They do affect the motorist seriously. The motorist's requirements are most difficult to meet and as the result of failing to meet them is likely to be very disastrous, the lighting of suburban roads should be designed largely with his requirements in view.

Mr. Charles F. Lacombe (By letter): Mr. Millar's paper takes up the factors necessary for the improvement of street lighting, the first two of which have been long hoped for and much discussed, while the third describes the variable factors which, while known to those who have worked on the streets in designing street lighting, have not been so carefully described and analyzed before.

Municipal appropriations, of course, limit the extent and quantity of illumination that can be obtained. As this item of a city's expenditures increases with its growth and develops increased business with load characteristics favorable to the producer, the city is entitled to a fair share of the increased efficiency of the light sources used without additional expense. A liberal policy of this kind on the part of the contracting company, with reasonable appropriations and a fair length of contract on the city's part, would go far towards the improvement of street lighting in the United States. If a city were shown what could be done in increasing the illumination by the use of the recent highly efficient lamps for about the same amount of energy, there is little doubt

that a term contract could be obtained justifying the expense of changed equipment and a considerable volume of increased business would ultimately result from the extension of the improved illumination so exhibited.

Speaking comparatively the more efficient lamps and accessories have arrived. The improved flaming and luminous arc lamps and the gas-filled tungsten lamp give the illuminating engineer lighting appliances of wide range that he has never had before in such completeness. This is due to the adaptability of the present lamps to all grades of illumination desired, largely resulting from the divisibility of the series gas-filled and multiple vacuum tungsten lamps throughout the lower ranges of intensity. A few years ago we had to work with only the indivisible arc lamp supplemented by the inefficient carbon incandescent lamp; the present range of resources in new and improved lighting units should prove a great incentive to the spread of good illumination on streets.

It is worth while to call attention to the availability of the 60, 80 and 100-candlepower series, gas-filled and vacuum multiple lamps for street lighting on several classes listed by Mr. Millar. My remarks on this are based on prices prevailing in New York city recently. In these smaller sizes of the tungsten lamp, we now have new units of an efficiency which can be economically used to replace enclosed arc lamps or gas lamps on residence or similar streets. Such lamps may be used to advantage on streets of classes 2b and 3a and are also available in many cases for classes 2a and 3b.

By choosing the proper sizes for a given height and spacing, excellent results can be obtained. With a reasonable height, say 14 to 16 ft. (4.26 to 4.87 m.), using good sized, white, slightly inclined reflectors and carefully arranging the reflector, lamp and socket so that the light source is well up towards and in proper focus with the reflector, glare can be diminished. This is particularly important in the use of gas-filled series lamps. Another form of reflector can be used to keep the direct rays of the light from the stoops or windows of houses. In fact the line of direct illumination can be controlled as to height within reasonable limits.

The use of two, three or four of these lamps within the old

spacings for enclosed arc lamps can usually be accomplished at a slightly less annual cost and improve the lighting without sacrificing the unidirectional effect which the tests made under Mr. Millar's direction for the National Electric Light Association and the Association of Edison Illuminating Companies have shown to be quite important. When gas lamps can be replaced by series gas-filled tungsten lamps on line and lamp poles, the annual cost is decreased with a large gain in illumination. On city streets with underground service several methods of installation can be utilized either with new or old equipment which will give increased illumination at a less annual cost per candle and at an equal or slightly increased cost of installation, compared with the cost of old equipment, depending on the economy of construction.

An installation of this kind as generally described, using overhead construction, was made by the writer about a year ago and afterward largely used in New York city. In this case 100-candlepower gas-filled lamps at a height of 14 ft. 6 in. (4.44 m.) from the road and spaced 120 ft. (36.57 m.) apart using white enameled reflectors (slightly inclined) gave in minimum foot-candles, measured on a horizontal plane near the street surface, 0.0146; maximum 0.551 and average of about 0.071, over a street and side walk 46 ft. (14.02 m.) wide. It proved very satisfactory for a 3a street, much more so than series enclosed 6.6-ampere carbon lamps and at a slightly smaller expense. The lamps in this case were placed on one side of the street only. In other cases the lamps were placed on both sides and staggered, the spacing being from 85 to 150 ft. (25.90 to 45.72 m.) apart along the curb, and very satisfactory results were obtained. The lamps were mounted on line poles. Wherever these arrangements were used on 2b and 3a streets they were preferred by the inhabitants to enclosed carbon arc lamps. They also proved satisfactory on many suburban boulevards or thoroughfares designated as 3b in the paper under discussion, and over fifteen thousand of these small lamps are now in use in New York.

Medium sized gas-filled lamps are available for all grades of 1b, 2a and 3b streets for all kinds of spacing and mounting heights, which are usually found already fixed. These lamps must be carefully selected as to intensity for spacing and height and used with proper diffusing globes or prismatic reflectors as

may be needed in each case. In these grades of streets and working into class 1a streets, luminous flame arc lamps are available and even more effective than the largest sized gas-filled lamps. The luminous arc lamps are particularly desirable when their full illuminating efficiency can be utilized. These more powerful lamps at considerable heights would also be used for the lighting of great squares, plazas or irregular spaces at diagonal intersections of important streets.

With this great range of light sources, admitting of many and accurate gradations in the lighting of various streets, it would seem that we might fairly begin to give an average and minimum scale of the illumination required on streets where silhouette or contrast lighting is not sufficient but where direct illumination, more or less powerful, becomes necessary as on 1a and 1b streets, particularly, and in some cases on 2a and 3b streets, where rapid and frequent motor traffic exists. Such a standard would be of great value for safety, as a gauge of responsibility in accident cases, and as a standard to which engineers may work safely. It would tend to so standardize the lighting of streets that there need be less changing of equipment and less interference with a properly designed lighting scheme by the idiosyncrasies of changing municipal administrations. A standard of this kind was described by Dr. Bell in his Johns Hopkins lectures* at Baltimore, and is seen abroad in the high minimum standards of important streets set by English and German engineers.

Mr. Millar in his paper and Mr. Sweet in another, have given valuable data and recommendations as to the avoidance of glare. These must be carefully borne in mind with the newer forms of lamps. In my experience, lamps of 100 scp. or under do not give a sufficient quantity of light to avoid glare by diffusing globes in commercial street lighting installations. In other words, the amount of light absorbed is too great in comparison with the whole to be economical. This is borne out by the results of careful tests in New York city with both series and multiple lamps. This should be borne in mind, particularly, with the gas-filled lamp with its small light source of great intensity, and glare should be taken care of by height, good sized white reflectors, and careful ad-

* Lectures on Illuminating Engineering, (1910).

justment of the position of the small light source and the reflector. The general practise in this country is to hang the lamps too low, and Mr. Millar's observations on height seem to bear this out. While the costs of higher iron ornamental posts for city use would be more expensive, such an installation using bare lamps with well designed good sized reflectors would be more economical in watts per candle output. The element of cost in this regard does not exist where lamps are suspended from or set on the poles of overhead lines. In my opinion, improved results would follow placing the newer types of lamps in such cases higher than formerly and dispensing with diffusing globes. The English and German practise follows this idea in both large and small units and it must be said that glare is not offensive in those installations which use bare lamps and reflectors, or with flame lamps with slightly cloudy globes or refractors, placed at heights of 24 to 30 ft. (7.31 to 9.14 m.). They thus obtain the utmost effect of their light sources and direct the rays downward and along the street, obtaining a high over-all efficiency. The same result could be obtained in cities in this country where there may be obtained the height necessary to avoid diffusing globes on lamps of high power.

The kind of pavements and their condition as Mr. Millar points out have a marked effect on the general appearance of a street lighting installation. This is most marked between a wet and dry pavement with the extreme contrast between the specular and diffuse reflection. Motor vehicle traffic has affected street lighting in many ways on account of the necessity of stronger lighting due to increased rapidity of movement and among these, its effect on pavements is very marked. It calls for a smooth surface pavement which is usually dark in color but becomes highly polished by traffic giving much specular reflection. Under extreme conditions this would approach the effect of a wet asphalt pavement. Under reasonably dry conditions with the usual amount of light colored dust always present, these pavements give a mild specular reflection of almost diffuse irregularity with the agreeable effect noted on Seventh Avenue, in New York. Under extreme conditions, though, it becomes a difficult problem to counteract the extreme darkening of the surface of a street or road. An instance of this occurred in 1913 in Central Park

where the former dust colored macadam roads were treated with oil and greatly darkened. A 50 per cent. increase in the candle-power of the incandescent lamps hardly offsets this effect. These roads were of course without any added illumination from private sources or from reflection from buildings.

Mr. Millar's emphasis on these variables in street lighting is well founded and shows that they must be taken into account seriously in street lighting work. The best way to study these variables is by trial installations on the streets themselves.

Mr. C. E. Stephens (By letter): The application of electrical energy in the production of street illumination, to my mind, is one of the most important subjects for consideration by scientific associations. More than any other piece of electrical apparatus, the street lamp is in the public eye. Its importance is not due to the value of this character of load as a market for electrical energy, but to the good or bad indirect effect on the electrical industry, resulting from whether our street lighting installations are good or bad.

Referring to possible improvements in street lighting, it seems to me that greater improvements can be expected in the immediate future, from a more scientific application of available light sources, rather than from radical improvements in the efficiency of available light sources. While the efficiency of light production is extremely low, the energy cost is also relatively low when compared with the capital charges for interest and depreciation on the fixtures, transmission, etc., and other items of cost that must be included. A further improvement in efficiency of the source of light would have to be very great in order to materially reduce the present cost of lighting. It is, therefore, a fitting time to carefully analyze the application of the source and to secure the most illumination possible from a given flux or volume of light.

Let us hope that such investigations as are at present being carried on by the electrical industry can be continued, to the end that a standard of street illumination will be set which will secure ample visual discrimination, with comfort, and a mental activity, necessary for safety; and further that the time will soon come when the doctors will agree.

Mr. G. N. Chamberlain (By letter): As a brief resume of the general conditions and limitations of street lighting and of

the particular problems before the street lighting engineer, this paper is the best that has come to my attention. The author has given a logical division of the subject; he has clearly outlined the different classes of street lighting and called attention to the various desiderata.

The difference in the nature of the street surfaces within the last few years and its importance upon the question of street lighting is very opportunely mentioned by Mr. Millar. The extensive adoption of such surfaces giving almost no diffusion, but a high degree of specular reflection, has brought about very different requirements and these must be met by the engineer if satisfactory results are to be obtained. The relative importance and effect of glare in street lighting is another most important matter. As is often the case with subjects given a great deal of prominence, it is possible I believe to over-estimate the effect of glare. A street so lighted that no light source is visible and the brightest visible part is the surface of the street near the lamp, certainly brings in no glare troubles, but is not a pleasing arrangement to the passerby. How far we should go in regard to cutting down the intensity of the light source and removing it from the line of vision is one of the problems that call for further investigation.

The question of large versus small light sources, while unsettled, is not as prominent as it was a few years ago, the general tendency being, as Mr. Millar points out, decidedly toward the larger units. The cluster arrangement of smaller units, so much in evidence a few years ago, is being almost entirely superseded by the single lamp standard. This change has been brought about by the introduction of the ornamental arc and the high candlepower incandescent unit.

Under the heading "Theoretical Considerations which have not been Demonstrated," Mr. Millar considers the subject of color and "animation" of the light source as one of individual taste and speculation. The engineers who have made the claims referred to have had extensive opportunities for tests and observation and have given expression to the decided advantages of color and animation of light sources. To the writer's knowledge, these two factors have determined the final selection of the lighting units supplied in several important installations.

GAS STREET LIGHTING.*

BY F. R. HUTCHINSON.

Synopsis: The following paper outlines the progress in street lighting by gas. Various steps in the development of gas lighting are described and illustrated.

It shall be my aim in, more or less briefly, covering this subject by illustration and description a few of the many styles of gas street lighting standards and lamps that have been designed and put in rather general use since the introduction of the old flat gas lamp.

Some comparisons in candlepower are given in the following paragraphs, but all are not mentioned as complete data were not available at the time of preparing the paper.

Fig. 1 pictures the flat flame gas lamp. On a consumption of 6½ cu. ft. of manufactured gas per hour, this lamp developed a lower hemispherical candlepower of 27.

Fig. 2 shows type of incandescent mantle street lamp, best known as the "boulevard lamp," most commonly used following the introduction of the incandescent gas mantle. This style of lamp is to-day still popular and there are more gas lamps of this design now in use than any other kind in America. The boulevard lamp develops a lower hemispherical candlepower of 64 and consumes 3½ cu. ft. of manufactured gas per hour. It is a well known fact that considerably greater efficiency is obtained with the mantle lamp than with the old flat flame burner. With but little more than half the gas, about two and one-half times the light is secured.

Unfortunately American municipalities, usually space lamps in accordance with their appropriations, which are generally small,

* A paper read at a meeting of the section of the Illuminating Engineering Society, May 7, 1915.

rather than as they should to get the best results. In America gas street lamps are spaced from 100 to 200 ft. apart; in European cities about 65 ft. apart, situated usually 100 ft. diagonally apart measured from lamp to lamp.

When the inverted gas burner came into general use for indoor illumination, its economy was so pronounced in comparison with the upright burner that both manufacturers and municipalities began looking into its application for street lighting.

One mantle of the inverted type does not look well in the boulevard lamp, so a burner was designed to suspend two mantles as shown in Fig. 3. This burner consumes about 5¾ cu. ft. of manufactured gas per hour and develops 182 mean lower hemispherical candlepower.

Following the introduction of the inverted gas burner, and its application in the "boulevard type lamp," experiments were made and lamps designed of various mantle units and of somewhat ornamental appearance. One of the first of such types is that shown in Fig. 4.

The post or standard was known as the "Boulevard," bearing the same name as the lamp illustrated in Figs. 2 and 3. On this post was suspended a three mantle gas lamp with a reflector shade. This lamp developed 400 candlepower (mean lower hemispherical) on a consumption of 11 cu. ft. of manufactured gas per hour.

A somewhat more ornamental post was next constructed which suspended two, three-mantle gas lamps equipped with elaborate globes and clear outer skirts as shown on Fig. 5.

The candlepower of these lamps was considerably lower than that of the lamp shown in Fig. 4, as the lamp in the latter case was fitted with a shade and equipped with a clear globe, while the lamps shown in Fig. 5 were fitted with clear outer skirts and alabaster globes. The gas consumption was the same.

Another style of standard and lamp is shown in Fig. 6. This standard may be equipped with three or five lamps each containing one or two mantles as desired. With all lamps lighted, this standard equipped with two mantles to each lamp consumes

22 cu. ft. of natural gas or about 37 cu. ft. of manufactured gas per hour. The candlepower is not known but claimed to be 1,000 with all mantles lighted.

Fig. 11 is a night view of a street showing the lamps and standards illustrated in Fig. 6 lighted.

Fig. 7 illustrates a lamp which is used between street intersections and Fig. 8 a standard for street intersections. (See Figs. 12 and 13.)

The lighting unit in these lamps consists of a double inverted fixture containing two mantles. On a manufactured gas consumption of 6 cu. ft. per hour each lamp produces 150 candlepower (mean lower hemispherical). With natural gas, considerably higher efficiencies are obtained.

The "Sixth City," Cleveland, O., not wishing to be outdone by any of its neighbors has, through its energetic and ingenious lighting superintendent, designed and is now using for its east side parks and boulevards ornamental lamps of the type shown in Fig. 10.

All these lamps are at present equipped with an automatic clock attachment that lights and extinguishes the main burners from a pilot light that is constantly burning. Fig. 15 shows a two-mantle burner equipped with a clock attachment fitted to the supply pipe.

Each lamp consumes 4.7 cu. ft. of natural gas per hour and develops about 135 candlepower.

Fig. 17 shows the construction of a recently designed automatic pressure valve—not yet tried and proven in actual use—which is intended to displace the automatic clock device now used for lighting and extinguishing lamps. This valve, also shown fitted to burner in Fig. 16, operates by increasing and decreasing the gas pressure in mains supplying lamps on park boulevards. The details of operation are indicated in Fig. 17. (Gas supply enters valve through 12 at pressure of five ounces pressure and raises diaphragm which in turn raises valve point 10 allowing gas to enter passage way 2 to lamp. At this pressure pilot is supplied with gas through 3. When pressure is reduced to one ounce, pressure is not sufficient to raise diaphragm which seats valve point 10 in seat between 1 and 2. Hinged trip 5 which might be termed "low pilot valve" is released when pressure is reduced

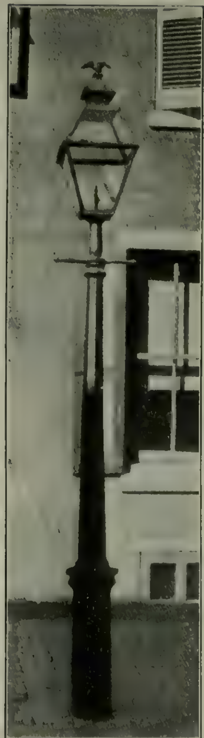


Fig. 1.

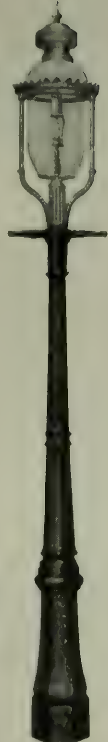


Fig. 2.

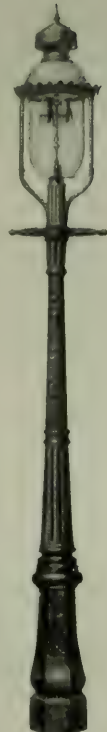


Fig. 3.

Fig. 4.

Fig. 5.

Gas lamp posts.

Fig. 6.

Fig. 7.

Fig. 8.

Fig. 9.

Fig. 10.

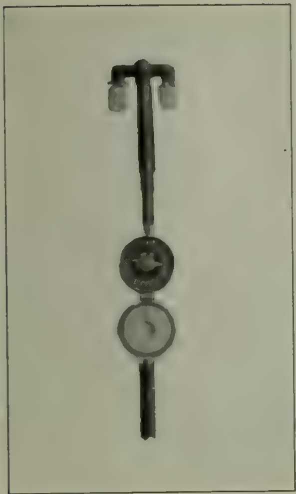
Gas lamp posts.

Fig. 11.—Night view of an installation using equipment shown in Fig. 6.

Fig. 12.—Showing type of equipment for street intersections.

Fig. 13.—Gas lighting installation on Delaware Avenue, Buffalo, N. Y.

Fig. 14.—Gas lighting at Panama-Pacific Exposition.



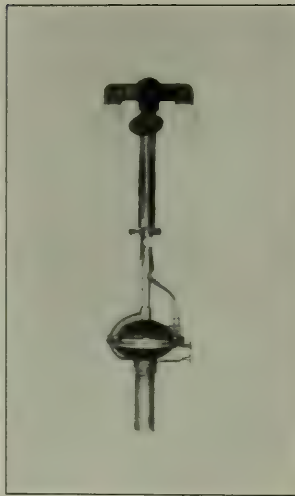


Fig. 15. Fig. 16.

Automatic clock lighting attachment for gas lamps.

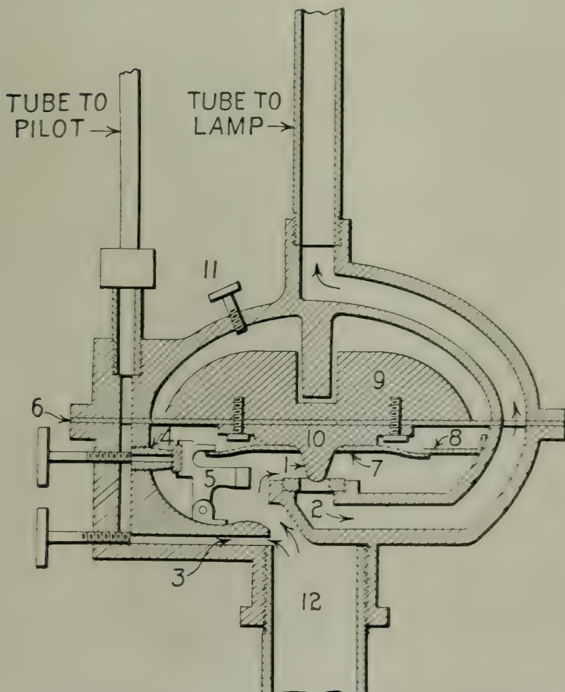


Fig. 17.—Diagram of automatic clock lighting attachment.

Fig. 18.—Gas illumination at the Panama-Pacific Exposition.

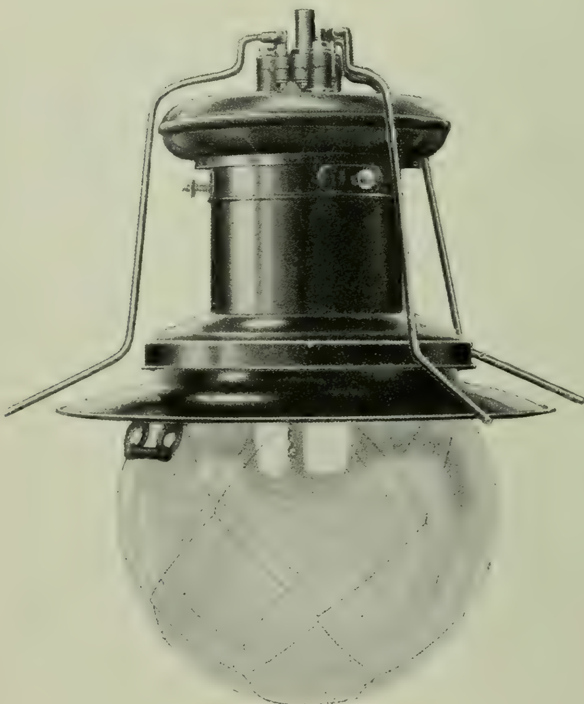


Fig. 19.—A three-mantle, high pressure gas lamp.

from five to one ounce, which permits gas at this low pressure to flow through 4 to pilot, maintaining substantially the same flame on pilot as with five ounce pressure, without permitting any gas to flow to main burner. Description of parts and ports: 1—area or passageway for gas to main burner at five ounce pressure and pilot burner at one ounce pressure; 2—continued port or passageway to main burner; 3—port or passageway to pilot for five ounce pressure; 4—port or passageway to pilot for one ounce pressure; 5—hinged trip or low pilot valve; 6—oiled leather diaphragm; 7—spring attached to 10 to close low pressure pilot valve; 8—brass stop to equalize tension of spring 7; 9—balance weight to close valve point with one ounce pressure; 10—main valve; 11—flash governing screw to release air from chamber above diaphragm; 12—gas passageway for service entering lamp post.)

GAS LIGHTING AT PANAMA-PACIFIC EXPOSITION.

Fig. 14 shows a close view of a post and lantern equipment used at the Panama-Pacific International Exposition for the lighting of the "Zone." These lamps are equipped with a mercury valve for distant control. The posts are located 75 ft. (22.86 m.) apart. All gas supplied to the exposition grounds is conveyed in the mains at 30 pounds pressure. A by-pass cock is installed in the box seen at base of the post where there is also a governor to reduce the pressure to that of a 5-in. (12.7 cm.) water column. All gas lamps are screened by specially designed lanterns of various types. These lanterns consist of a wooden frame covered with canvas in either pink or orange color and at night the illuminating effect is very beautiful. All entrances and exits to the exposition are gas lighted, the entrances by three and five-mantle gas lamps, the exits by one-mantle lamps.

Fig. 18 shows a night view of the "Zone." (Note the different shapes and designs of lanterns surrounding the gas lamps.)

In the State and Foreign Area of the exposition the street lighting is done with high pressure gas lamps. Fig. 9 shows a standard and lamp. These lamps are mounted on posts 18 ft. high. Gas is delivered to lamp at 3 pounds pressure. The mean lower hemispherical candlepower is 1,160; the consumption is 24.30 cu. ft. (0.68 cu. m.) manufactured gas per hour.

Before leaving the subject of high pressure,—Fig. 19 shows

a foreign three-mantle high pressure gas lamp which develops a candlepower of 4,000 on a natural gas consumption of 35 cu. ft. (0.96 cu. m.) per hour. On a short life test made on this lamp from March 4 to 16, 1915, during a burning period of 160 hours, but one mantle was replaced through breakage. No globes or other parts were replaced. The gas (natural) delivered at this lamp was at the rate of 35 cu. ft. per hour at 2-lb.

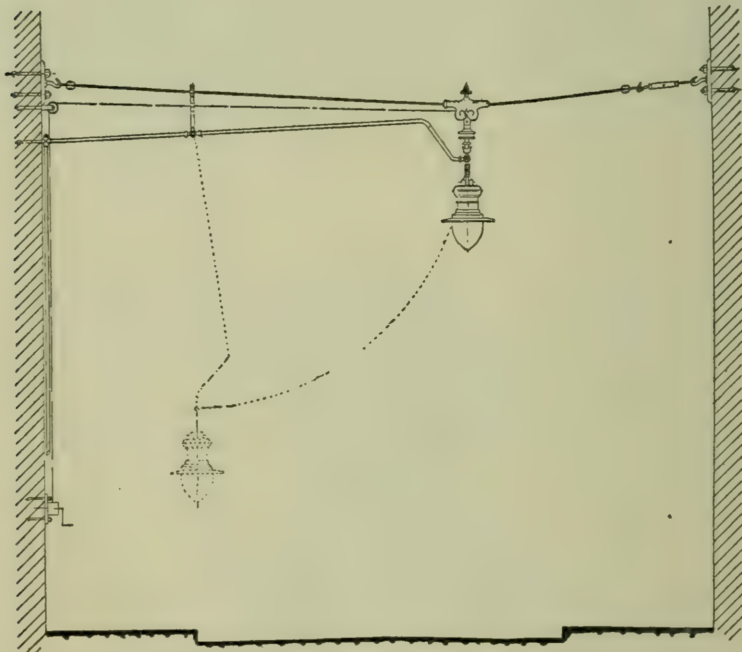


Fig. 20.—Method of suspension for gas lamps on streets not having overhead trolley wires.

(1.36 kg.) pressure. In street illumination abroad, this lamp is located in the center of the street about 30 ft. (9.14 m.) from the ground. Figs. 20 and 21 show the manner of suspending gas lamps over the center of street and the lowering gear. The construction shown in Fig. 20 is used where there are no overhead trolley wires on streets not exceeding 80 ft. (24.38 m.) in width. The arrangement shown in Fig. 21 is for street crossings having overhead trolley wires. The lamp is moved to the side and then

lowered. Flexible metal tubing is used from an ell at the top over to the lamp.

There are many other styles of standards and lamps than those illustrated in this paper, but I have tried to select examples of most kinds in somewhat general use.

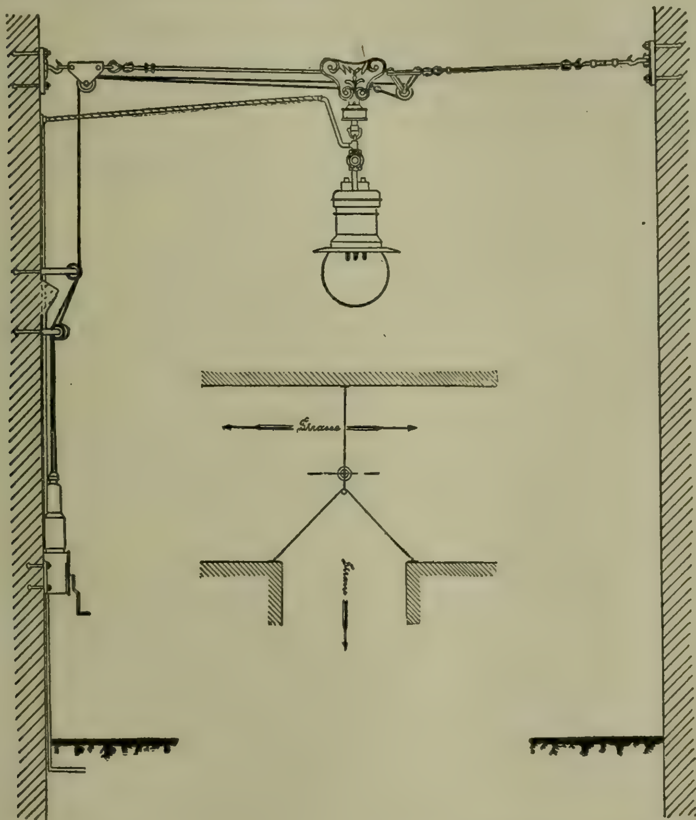


Fig. 21.—Method of suspending gas lamps on streets having overhead trolley wires.

The United States has been slow to adopt high pressure gas street lighting and it will probably be many years before it becomes very generally used, but time here, as well as abroad, will see it in much more common use than now. The excellent quality of light, high candlepower and economy of operation will be recognized, and when it is, our fellow electric members of the Society will have to look out for their laurels.

SHEET GLASS IN LIGHTING.*

BY EDGAR H. BOSTOCK.

This subject can best be treated under two principal divisions, namely: (1) factory operations in the production of sheet glass; (2) variations that can be made in the glass.

This will give an understanding of what results can or cannot be readily obtained, and perhaps some idea of the advantages and limitations of sheet glass as applied to fixture manufacture.

FACTORY OPERATIONS.

The factory operations herein described are those employed in a Kansas factory, where the low price of gas from the adjacent gas fields is very favorable for the manufacturer. The gas is supplied through a 10-in. main, this particular factory consuming about 1,500,000 cu. ft. of gas per day.

Sheet glass is made in a tank furnace the inside dimensions of which are usually 18 to 20 ft. in width, by 45 to 60 ft. in length. Such a furnace when in full blast contains anywhere from 300 to 400 tons of molten glass.

The furnace contains two recesses—one through which the gas passes and the other admitting the air. The gas and air come together so as to burn across the furnace. There are two sets of flues filled with checkerwork, one set of which carries off the exhaust gases while the other heats the entering gas. The furnace is arranged so that the fire can be reversed, and the heat accumulated in the checkerwork from the exhaust gas, utilized in heating the entering gas and air. By this means a much higher temperature can be secured than if the fire were fed with cold air and gas.

This furnace heats the glass from the top down, rather than from the bottom up, and there are particular reasons for so doing. The specific gravity of clay is less than that of molten glass, so that to keep the bottom in the tank, it is necessary to heat

* A condensed statement of an illustrated talk given at a meeting of the New York Section of the Illuminating Engineering Society, May 25, 1915.

from the top. The bottom of the tank is heated hardly to redness, and the denser glass remains at the bottom.

The molten glass flows off from the upper surface to the outlet from which it is worked. A ring of clay floats on the glass in

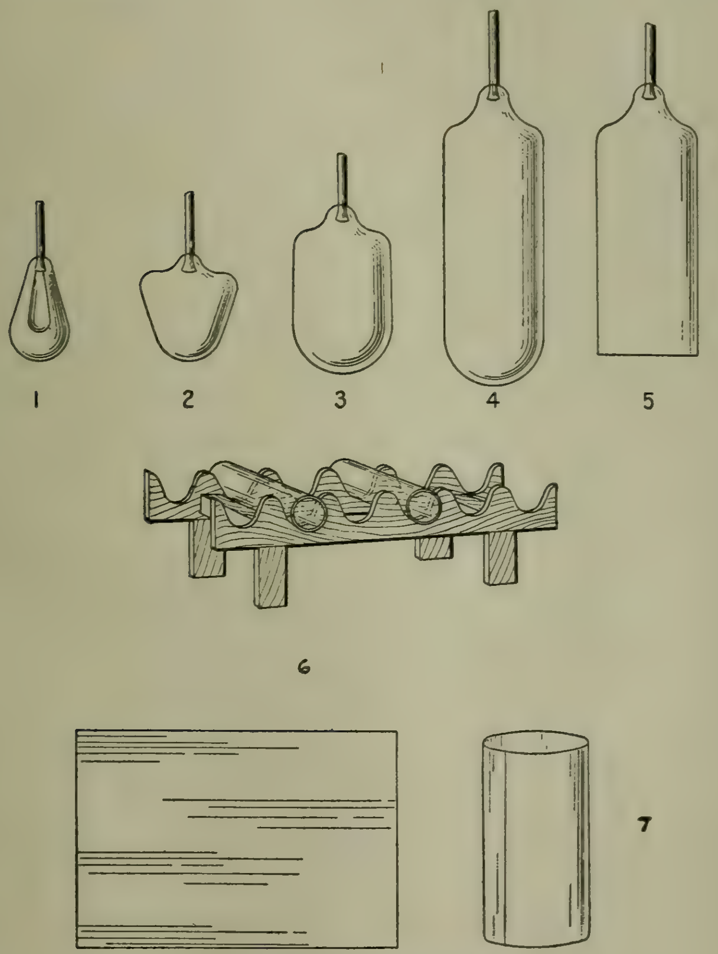


Fig. 1.—Steps in blowing sheet glass.

front of the working holes, and serves to stop the flow of glass. The glass is melted from a mixture of sand, limestone and ground carbon with a certain proportion of old broken glass. The mixture is inserted in the furnace by means of the long handled

shovel. To protect his face from the heat, the workman wears what is called a face board, which is held in place by a plug inserted between his teeth.

Fig. 1 shows the method of working the glass in blowing and forming a sheet. The workman employs an iron pipe about 50 in. long, the end of which is heated to a slight redness so that the glass will adhere to it. Glass may have to be gathered six or seven times, depending upon the size of the article to be made and the density of glass. When a sufficient quantity is gathered, the workman blows down the pipe forming a bubble inside the molten glass. This is formed by swinging and rotating, the pipe being rested part of the time on an iron block or "lazy-jack." In blowing, the workman takes advantage of the expansion of heated air, at proper intervals holding his thumb over the end of the pipe instead of blowing. As part of the glass bubble cools and hardens it is reheated and the operation continued. Owing to the mass of glass, the lower part of the bubble retains its heat longest. The cylinder is formed by rolling the bubbles on an iron table. When the proper shape is secured, the further end is blown open the cylinder placed on an iron horse and the cap removed.

The cylinder is then carried to another secondary or flattening oven, cracked open lengthwise, opened and flattened out on a sheet of very highly polished clay. The workmen are very expert and the sheet so produced is usually approximately of the size desired. In fact a workman gathering 16 lbs. will gather all day without varying more than 2 or 3 oz. They will make sheets to cut 40 by 60 in. with little more than the necessary allowances, and the cylinders will not vary more than 1 in. in circumference from end to end. Considerable physical endurance is necessary for the pipe weighs 12 to 15 lbs., and the glass bubble out at the end may weigh 20 or 25 lbs.

In cracking the cylinder for removing the cap, a thread of hot glass is laid on the cylinder long enough for local heating and then the proper point is touched with cold metal, perhaps an iron strip and the glass cracks along the heated thread.

In splitting open, the workman will take a rod of iron heated at one end, with some carbon to prevent scratching, and work the iron up and down the cylinder. With the cylinder at just the

right heat, one extreme edge is touched with his wet thumb, which starts a crack that follows the iron practically the full length of the cylinder. The heat in the flattening furnace is just sufficient to render the glass malleable, say about 500° C. The flattened glass passes to the annealing furnace, through which it is carried on rollers.

Another kind of sheet glass is manufactured by the casting and rolling process. In this a "pot furnace" is used, in which pots about 45 in. in diameter are filled with the glass mixture and heated. When all are ready the workmen lift out the pots and carry them to a casting table, pouring out the molten glass on the table and rolling it out to the required thickness with heavy rollers, one, two or three pots being used, depending upon the size of the sheet required. This method is used for making large sheets of plate glass. Such sheets are usually cast and rolled to a thickness of ¾ in., and later ground and polished down to ¼ in. When glass is manufactured in thick plates it is necessary to anneal it very carefully, and therefore as soon as the plate has been rolled, it is taken to an annealing oven. These ovens are often 400 to 500 ft. in length, and a large plate may be kept in such an oven from 7 to 10 days before it is thoroughly annealed.

When the sheet is annealed, it is polished by electrical machinery, first with rough river sand and then successively with a finer sand, emery and rouge. Curious to relate, after the finest mechanical polishing, it is necessary to re-polish portions of the plate by hand.

All the plate glass which is manufactured is ground down from ¾ to ¼ in. in thickness, in order to remove any inequalities and warping which may be present.

Figured rolled glass is made by a slightly different process. In this a printing roller is used instead of a plain one. After the glass is rolled by the smooth roller into a sheet the printing is put on by rolling a figured roller over the plastic glass.

Another process which will be of interest, although not a method of manufacturing glass plates, is the pressing of glass into various shapes. In this the workman gathers a certain amount of glass upon an iron rod and puts it into a mold; a second workman watches the mold and when it is filled to the

proper height he cuts the thread with a pair of sheers. A cap is then placed on the mold and it is pushed under a plunger which is forced down into the mold forming whatever article may be necessary.

A new process which has recently come into existence is that of making window glass by machine. It is more or less successful depending upon whether one makes hand-blown glass or machine-blown glass. In any event, the inventor of this has followed very closely the hand-blown process. It takes an expert to tell the difference between the machine and hand-blown glass today.

These are some general processes which it is necessary to understand in order to comprehend some of the more complicated methods which are in use for making the various glasses used by illuminating engineers.

In making colored glass, or glass designed to shut out certain light rays, there are some further processes which have to be taken into consideration. One common process is that of manufacturing flashed glass, a clear glass coated with a film of colored glass upon one side. To produce this, the workman when he first starts to "gather" dips his pipe in a small pot of colored glass of the color desired, for the first and possibly for the second "gathering." He then carries his pipe to a pot of crystal glass and "gathers" on top of the colored glass the necessary amount of crystal glass to form the sheet or the article that he is going to blow out. As he blows and forms the different articles the skin of the colored glass remains on the interior of the cylinder, and will be distended to whatever thickness of film he wants according to the quantity of colored glass that he has gathered. By this process blown glass of various color densities can be manufactured according to the thickness of the film of color that is used.

Silver reflector glass is manufactured in the same way as sheet glass up to the point where the workman blows the ball of glass. The workman then thrusts the ball into a clam shell mold upon which has been machined a series of lines, all ending in a common point at the bottom of the mold. He then blows his glass into the ribs of the mold. Compressed air is sometimes

used for this process. The ball is then taken back to the furnace, reheated and swung out in the cylinder where the marks upon the ball are followed in cutting the cylinder. The skill of the workman is brought into play to keep the line in exactly a horizontal direction.

Crackled glass is made by a variation of this process. The workman proceeds as before until he has the ball blown when he thrusts the bottom of it into a receptacle containing water. This must be done very carefully for if the glass ball is immersed too deep it will crack. After reheating it, the cracks are melted together except just upon the skin where they have broken through. When the glass is swung out into the cylinder, the crackled marks being swung out with the cylinder, the plate becomes crackled glass.

Muffled glass is made by the same general process except that the blowing process is continued until the cylinder is formed when it is dropped in a two-piece mold which closes upon the cylinder, the workman blowing the glass inside the mold. He then produces upon the cylinder whatever marks may be cut in the mold.

The necessity for annealing glass referred to before will be understood when it is realized that a sheet of glass of any thickness at all cools much faster upon the outer skin than it does within. Of course, in very thin glass it is of very little importance but in glass of any thickness at all, even of one millimeter, a strain is caused by the quick cooling of the outer skin which is sometimes very uneven. It is possible to have a glass that will not stand even the extremes of temperature in our own climate here because it is not well tempered, and this problem increases with the thickness of the glass because of the internal stress set up is much larger. As an illustration of this point, glass tears are sometimes made by dropping extremely hot molten glass into a bucket of cold water, the skin of the glass being chilled immediately while the interior is clear red. These tears may be laid upon the floor and hit with a sledge hammer without effect on account of the extreme hardness of the outer skin, but if by any chance the outside skin is scratched at any point it will effect the internal structure, the internal strains are so great that

the "tear" is immediately reduced to a powder. This is exactly what happens when a glass ball or a heavy blown globe is not properly annealed. It may stand extremely hard usage, but when once the surface is scratched, the ball is broken on account of the unequal stresses.

*The writer became interested in the subject of sheet glass through the influence and kindness of some of the members of this Society. At that time there was very little known about the subject. Illuminating gas was first used extensively in the Soho Works of Watt and Bolten in Birmingham, England, and just three miles from the works of Watt and Bolten stands the large glass works of Chance Brothers & Company. It is very likely that the first sheet glass used in lighting was made to protect the gas jet burners used at the Watt and Bolten Works.

There was very little further use made of sheet glass in lighting until the time of electric lighting, as the small gas flames used did not require very much protection.

One of the first instances that the writer remembers of the use of sheet glass with a definite view of improving lighting conditions occurred in the equipment of the United Engineering Building. In the ceiling lighting of the auditorium on the second floor Mr. C. E. Knox devised the first large installation of ceiling or dome lighting. He did not know what glass to use, as those available were very few, so the glass chosen for this installation was a crystal ripple, sand blasted. It was the only thing available of any diffusive power that he could place between the lamp and the line of the ceiling. He desired to keep the lamp out of view and attained it by grinding one surface of the glass. The difficulty was that a cleaning problem was introduced which will probably exist as long as the installation remains.

The next large installation that came to the writer's attention was the lighting of the Soldiers' Memorial Building at Pittsburgh, by Mr. Bassett Jones. Mr. Jones went into this problem very extensively and measured the absorption and refraction of a number of the various glasses. It was the intention to produce a warm glow rather than a cold white light and therefore a glass

* The remainder of this lecture was illustrated by means of a number of sheets of glass illustrating the various points discussed by Mr. Bostock. As no illustrations are available, these cannot be shown.

was chosen in which the color is not apparent, such a slight amount of tint was included; so that while the absorption is only 10 per cent., the effect is that of warmth when the lamps are turned on. Tungsten lamps were just coming into use when this installation was planned. Two types of glassware were used in this installation in order to equalize the lighting. Certain conditions in the ceiling made necessary a slightly deeper tint of glass to increase the amount of amber light. This glass was molded so skilfully by the glass manufacturer that there is an appearance of uniformity over the whole surface. This difference is mentioned in order to emphasize the mobility of glass. The glass mixer is able to mix colors in order to reproduce any given intensity and shade.

Ten or fifteen years ago there sprang up an era of mosaic dome lighting and a good many domes, good, bad and indifferent were made without any regard to the illuminating value of the glass that was used in them. The glass makers, however, in making glass for these domes discovered certain facts in glass making, and when the demand came for a diffusing glass to be used in the new indirect lighting they were able by making a mixture of opal and flint glass to turn out the glass which is now known as the "alabaster" type. This glass is made by mixing a given amount of opal and flint glass upon the casting table and rolling the mixture in the same way that plate glass is rolled. The glass mixer is able to vary the absorption of this glass by varying the quantities of the ingredients. If, for instance, a certain type of indirect dish is to be made in which it is necessary to have 60 per cent. absorption, the glass manufacturer simply figures out how much opal glass and how much flint glass will give him that 60 per cent. combined absorption and reflection. It is possible to do almost anything with this type of glass; second and third colors may be added, the opal may be tinted, and the flint may be tinted.

Some six or seven years ago the writer became interested in trying to do away with the great problem caused by the surface of acid etched glass. The particular installation that was brought to my attention at that time was the installation of lanterns around the then new Pennsylvania Terminal. These

had been glazed with ground glass and the cleaner was apt to take a greasy rag to clean the glassware. The glass of course was soon streaked with all shades of grey and black and it would be impossible to even venture a guess as to how much light absorption had been added to the original glass. The problem at that time was to find a glass in which the same effects would be obtained as with ground glass, and yet a glass which was as readily cleanable as window glass.

The glass which was finally adopted is made by a process which produces a glass plain on one side and flashed with any required color on the other side. The glass in this installation is flashed with opal and as it was made to duplicate ground glass, it has about 30 per cent. absorption. It is possible, however, for this glass to be produced with absorptions of from 20 to 60 per cent. This glass can be cleaned just as easily and as readily as window glass.

Some four years ago when Mr. D'Arcy Ryan was planning the lighting of the Panama-Pacific Exposition Buildings, he was confronted with the problem of illuminating the windows of buildings which were lit by flood lighting so as to eliminate reflecting points of light. One of the first troubles he discovered was that when the windows are set rather deep in the facade, the windows appear as black spots due to the fact that light passes through the window plate at 90° and therefore is not reflected. The problem was to glaze the windows with a glass having the same luminosity under flood lighting as the rest of the facade. A new type of glass was produced through research work by Mr. Jones called "Deflex" glass. This, he found, set up the maximum amount of specular reflection, and is the one which was adopted by Mr. Ryan for the exposition buildings. With the modification of a wire content this was used for the dome at Horticultural Hall where Mr. Ryan obtained such wonderful effects.

Last year Mr. Edwards of the National Lamp Works presented at our 1914 convention a paper on the lighting of rooms through translucent glass ceilings, in which he gave the results of his tests of several different glasses. It is interesting to know that Mr. Edwards was led into this work by the desire of the

National Lamp Works to glaze the rooms of their own buildings at Nela Park with a glass which would give a maximum diffusion so that the points of light from lamps within the room could not be observed from the outside. Mr. Edwards picked out a rolled glass which is very beautiful in design and workmanship, and which sets up very good diffusion, and is at the same time an artistic glass. The glass has about 54 per cent. transmission which, considering the fact that it is of such a definite pattern, is a highly efficient glass. It became evident after the test conducted by Mr. Edwards had been undertaken that a different theory of light diffusion in sheet glass could be evolved. Crystal glass is, of course, the ideal glass in use for such installations because of its small absorption. In all tests which were made wherever a glass whose deflective surfaces were cylindrical in shape, it was found that a better diffusion was secured. As long as a definite sharp angle was present a direct reflection was noticeable from the angle of the glass without transmission, and therefore, maximum diffusion was secured by making all reflective surfaces cylindrical in shape. A new glass was, therefore, devised from this acquired data and the manufacturers are now making a rolled glass which contains a series of small semi-cylindrical projections. It was thought at first that it was not possible to roll this glass making these semi-circular projections touch each other, and a small flat plane was left between each projection so that it is not a perfect diffusive glass. It is the writer's opinion, however, that the right theory is being applied to produce a perfect diffusing glass. This is the glass that was used in the crow's nest in the Woolworth Tower and it is being glazed under the direction of Mr. Madgsick. This is the last word which we have in sheet glass for diffusion of light to-day.

One other application of sheet glass to illuminating engineering has been evolved quite recently. It is a new method of sign lighting built upon multiple reflection of light. Fig. 2 illustrates the sign made up and the principle upon which it depends. The sign is lighted by means of a line lamp and the theory upon which it is based is that if the incident angle of the entering light remains within the reflective angle of the glass it has been thrown on, the light will be reflected back and forth within the glass and will not leave it. Now if this were a plain piece of glass it would

not be apparent to the eye that there was any light there at all except at the edges where the light escaped. If now the surface of the glass is abraded by any means at all there is set up a different angle of reflection at that point and so the light is visible

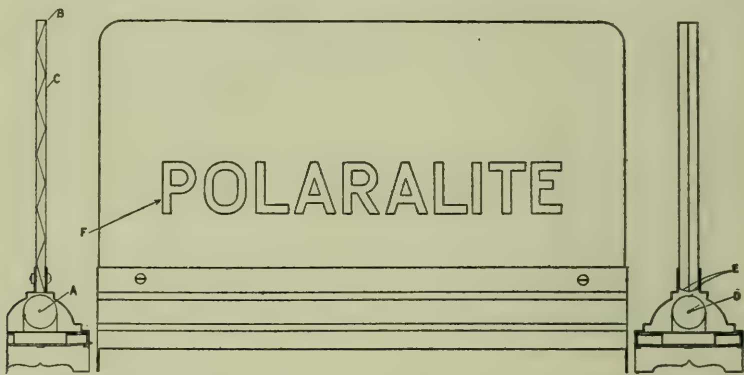


Fig. 2.—Diagram of sign. *A* and *D*, wire of straight-filament lamp. *B* and *C*, path of light rays confined within reflective surface of glass. *E*, face of glass in double sign so metered as to bring path of light within refractive angle of glass. *F*, abraded surface, where light becomes visible.

at the particular point where the angle changes. In the first experiments merely the surface of the glass was abraded, but better results are attained by cutting the glass deeply. These signs have recently been put on the market.

SOME EXPERIMENTS ON THE EYE WITH INVERTED REFLECTORS OF DIFFERENT DENSITIES.*

BY C. E. FERREE AND G. RAND.

Synopsis: In previous papers read before this society by the present writers, the gradation of surface brightness and its distribution in the field of vision were shown to be important factors in the effect of lighting conditions on the eye. In the work described in the present paper, gradation of surface brightness is made the chief variable. Inverted reflectors of six degrees of density are employed, and a correlation is made between the illuminating effects obtained and the tendency to cause loss of power to sustain clear seeing and to produce ocular discomfort.

INTRODUCTION.

This paper is the fourth in a series in which the effect of different conditions of lighting on the eye is investigated. In the first paper, two tests were described—one designed to be used as a general test for detecting the comparative tendencies of different lighting conditions to cause a loss in the eye's power to sustain clear seeing for a period of work; the other for detecting the tendency to produce ocular discomfort. In the second paper, the application of the first of these tests to various lighting conditions was begun. Two purposes were had in making this application: (1) the studying and perfecting of the test itself for use in lighting work, which it is obvious could not be done effectively under one set or type of lighting conditions;[1] and (2), the investigation of pertinent lighting effects, the results of which could be made both to serve as a guide for further work, and to provide cumulative data from which conclusions may be drawn as the conditions and stage of advancement of the work may warrant. This paper was divided into two sections. In the first the test was applied to the determination of the effect on the eye of three lighting installations, direct, semi-indirect and indirect, so selected as to give wide differences in illuminating effects. In the second section the effect of six variations in intensity for the direct and semi-indirect installations was determined. In both

* A paper presented at the ninth annual convention of the Illuminating Engineering Society, Washington, D. C., September 20-23, 1915.

of these cases the tests were all made at one position in the room, the point marked as the position of the observer in Fig. 1 of the present paper. Obviously, however, the effect of an unfavorable installation on the eye will vary with the position of the observer in the room. In the third paper, therefore, the tests were repeated for these installations at four positions in the room: the first with six reflectors in the field of view; the second with four; the third with two, and the fourth with none. The following features were also included: the work of the intensity series was completed, *i. e.,* six intensities of light were used with the indirect reflectors; a test was described for determining the effect on the fixation muscles of the eye; and a series of miscellaneous experiments was conducted pertaining to the hygienic employment of the eye. In these experiments the following points were taken up: the effect of varying the area, and conversely the intrinsic brilliancy of the ceiling spots above the reflectors of the indirect system of lighting used; the effect of varying the angle at which the light falls on the work in a given lighting situation; the effect of using an opaque eye-shade with dark and light linings with a number of lighting installations; the effect on the efficiency of the fixation muscles of three hours of work under each of these installations; the effect of motion pictures on the eye for different distances of the observer from the projection screen; and a determination of the tendency of the different conditions of lighting used in these experiments to produce ocular discomfort, and a comparison of the tendency to produce discomfort and to cause loss of efficiency.

Time cannot be taken here even for a brief statement of the results obtained in these experiments. For the purpose of this paper, it will be sufficient to say that gradation of surface brightness and its distribution in the field of vision were shown to be important factors in the effect on the eye. In the work to be described in the present paper, gradation of surface brightness has been made the chief variable. Inverted opal glass reflectors of six degrees of density have been employed and a correlation has been obtained between the illuminating effects produced and their tendency to cause loss of efficiency and to produce ocular discomfort. As the work progresses, an attempt will be made

not only to investigate this factor further in some of its more important relations to lighting practise, but to take up in turn, so far as is practicable, each of the other factors mentioned in the former papers.[2]

CONDITIONS TESTED.

An effort has been made to get a series of reflectors similar in size and shape and differing only in density. It is our ultimate purpose to use these reflectors both in accord with the principles of direct and indirect lighting, and by employing additional translucent and opaque reflectors, differing if need be in size and shape, to vary first one and then the other of the distribution factors mentioned in the former papers. So far, however, we have been able to use only six of the number of reflectors needed to carry out this plan, and these in accord with the principle of indirect lighting. They were all turned towards the ceiling and were installed the same distance from it. So installed, as the photometric measurements will show, the chief variables have been the brightness of the reflectors and the ceiling spots above the reflectors,—more especially, the brightness of the reflectors. The reflectors used will be designated here by the numerals, I, II, III, IV, V and VI; and will be described in greater detail in an appendix to the paper. They were all installed 30 in. (0.76 m.) from the ceiling[3] and were held by Plume and Atwood semi-indirect holders attached to cords dropped from the eight outlets shown in Fig. 1.

It has been our wish to conduct this investigation, as has been the case in all our work on the distribution factors, with the quality and intensity of the light made approximately the same. Unfortunately, with the material available, the quality of the light could not be made in all cases uniformly alike. Clear tungsten lamps were used as light sources with each installation, but two of the reflectors, I and II, were not free from color. The density of these reflectors had been secured in part, by giving them a brownish tone. Just how much effect this would have, if any, on the results of the tests we are not prepared at this time to say. The fact should be borne in mind, however, in considering the results obtained. It was decided to make the intensity of light as nearly equal as possible at the test object and to give a

supplementary specification of the lighting effects in the remainder of the room.

At the test object the light was photometered in several directions. It was made approximately equal in the plane of the test object and as nearly as possible equal in the other directions. The specification of the lighting effects in the remainder of the room was accomplished as follows. (1) A determination was made of the average illumination of the room under each set of reflectors. The room was laid out in 3 ft. (0.90 m.) squares and

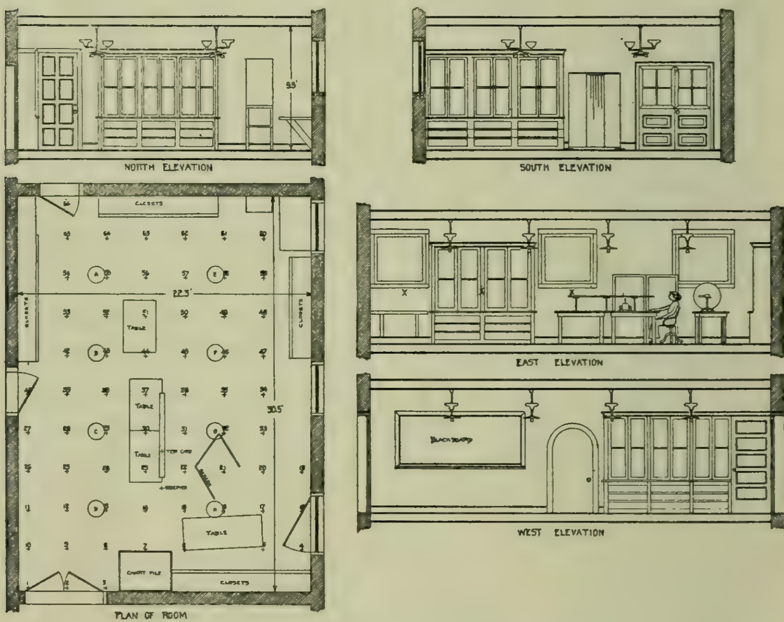


Fig. 1.—Plan of test room.

illumination measurements were made at 66 of the intersections of the sides of these squares. Readings were taken in a plane 122 cm. above the floor with the receiving test-plate of the illuminometer in the horizontal, the 45° and 90° positions, measuring respectively, the vertical, the 45° and horizontal components of illumination. The 122 cm. plane was chosen because that was the height of the test object. (2) A determination was made of the brightness of prominent objects in the room, such as the test card, the reflectors, the reading page, the specular reflection from

surfaces, etc. The brightness measurements were made by means of a Sharp-Millar photometer with the receiving test-plate removed. The instrument was calibrated against a magnesium oxide surface obtained by depositing the oxide from the burning metal on a white card. By this method the reflecting surfaces were used as detached test-plates. The readings were converted into candlepower per square inch by the following formula: brightness = foot-candles/$\pi \times 144$. (3) Photographs were made of the room for each set of reflectors employed. They will not all be included in this paper, however, because too little difference in illuminating effects is shown for the different reflectors to warrant so extensive a use of the photographic method of specification.

The tests were conducted in a room 30.5 ft. (9.29 m.) long, 22.3 ft. (6.797 m.) wide, and 9.5 ft. (2.895 m.) high. In Fig. 1, this room is shown drawn to scale: plan of room, north, south, east and west elevations. In the plan of room are shown the 66 stations at which the illumination measurements were made; and the positions of the outlets for the lighting fixtures, A, B, C, D, E, F, G and H. In the drawing, east elevation, the position of the observer at which the tests were taken is represented.[4] So far in the work with these reflectors the tests have been made at only one point in the room.

Table I gives the illumination measurements for each of the 66 stations represented in Fig. I. These measurements were made with the receiving test-plate of the illuminometer in the horizontal, the vertical and the 45° planes. Tables II and III have been compiled to supplement Table I for the purpose of making a comparative showing of the evenness of illumination at the 122-cm. level given by the six sets of reflectors. Two cases may be made of this: (1) a comparison may be made of a given component from station to station; or (2) the difference between the components may be compared. To facilitate these comparisons (*a*) the mean variation from the average of each of the components has been computed; and (*b*) the difference in the average of the three components has been determined. Results for the first of these points are shown in Table II; and for the second in Table III.

TABLE I.

Showing the illumination measurements in foot-candles for each of the 66 stations represented in Fig. 1 for the six types of reflectors used.

Division A.

	Horizontal, reflector type			Vertical, reflector type			45°, reflector type		
Station	I	II	III	I	II	III	I	II	III
1	1.40	1.35	1.30						
2	1.50	1.28	1.20						
3	1.49	1.52	1.27						
4	1.85	1.46	1.47						
5	2.40	2.20	2.0						
6	2.20	2.40	2.10						
7	2.60	2.50	2.30						
8	2.90	3.10	2.90						
9	2.70	2.60	2.50						
10	1.54	1.41	1.32						
11	2.10	1.88	1.78						
12	3.90	4.30	3.70	0.55	0.53	0.50	2.10	2.0	1.72
13	4.50	4.90	4.50	0.58	0.55	0.49	2.30	2.70	2.40
14	3.20	3.40	3.50	0.50	0.46	0.48	1.65	1.70	1.90
15	3.10	3.10	3.20	0.52	0.40	0.42	1.62	1.70	1.69
16	4.50	4.40	4.30	0.50	0.41	0.50	2.50	2.20	2.10
17	3.80	3.10	3.10	0.54	0.40	0.43	2.20	1.48	1.62
18	2.60	1.86	1.90	0.57	0.46	0.45	1.50	1.10	0.97
19	3.30	2.40	2.50	1.25	0.87	0.93	2.40	1.60	1.90
20	4.10	3.70	3.70	1.17	1.0	0.94	2.70	2.20	2.20
21	5.20	4.60	4.50	1.30	1.30	1.22	3.10	2.90	2.70
22	4.0	3.50	3.80	1.16	1.0	0.94	2.50	2.20	2.30
23	4.0	3.70	3.70	1.10	1.06	1.20	2.60	2.30	2.10
24	4.90	4.90	4.70	1.1	1.20	0.97	3.0	2.70	2.80
25	3.90	4.10	4.20	1.03	0.91	0.95	2.40	2.30	3.30
26	2.50	2.10	1.78						
27	2.80	2.80	2.40						
28	4.80	5.85	4.70	1.15	1.05	1.20	3.40	3.0	3.20
29	5.80	6.0	6.20	1.34	1.35	1.25	3.80	4.0	4.0
30	4.50	3.80	4.50	1.42	1.11	1.37	3.40	2.70	3.10
31	4.50	3.90	4.60	1.42	1.15	1.14	3.30	2.50	3.0
32	5.60	5.30	5.60	1.42	1.33	1.32	4.0	3.70	3.40
33	5.0	3.60	4.25	1.52	1.10	1.15	3.30	2.60	2.80
34	4.70	3.80	3.80	1.86	1.54	1.42	3.70	2.90	2.80
35	5.20	4.90	5.0	2.10	1.64	1.60	4.40	3.50	3.80
36	4.50	4.10	4.50	1.80	1.61	1.48	3.60	2.80	3.30
37	4.60	4.0	4.60	1.99	1.54	1.66	3.70	3.0	3.50
38	4.90	5.40	5.40	2.0	1.90	1.80	4.0	3.80	4.20
39	4.10	4.10	4.0	1.72	1.68	1.50	3.20	3.10	3.20
40	2.60	2.40	2.0						
41	2.0	1.67	1.62						

TABLE I.—(*Continued.*)

Station	Horizontal, reflector type I	II	III	Vertical, reflector type I	II	III	45°, reflector type I	II	III
42	3.90	4.40	4.40	1.80	1.60	1.64	3.40	3.20	3.40
43	5.40	5.40	5.60	2.20	1.86	1.84	4.70	4.0	4.40
44	4.40	4.10	3.70	2.10	1.76	1.50	4.0	3.40	3.20
45	4.10	4.30	4.20	2.10	1.71	1.68	3.80	3.40	3.30
46	5.20	5.60	5.70	2.10	1.60	1.68	4.60	4.10	4.40
47	4.50	4.20	4.50	1.76	1.58	1.52	3.60	3.30	3.30
48	3.90	3.70	3.80	2.0	1.94	1.76	3.60	3.30	3.30
49	4.90	4.80	5.10	2.30	2.10	2.0	3.90	4.20	3.80
50	4.10	3.60	4.0	2.30	2.0	2.10	3.80	3.50	3.40
51	3.90	3.70	3.90	2.30	1.90	1.98	3.70	3.30	3.50
52	4.40	4.50	4.60	2.30	1.95	2.0	4.10	3.70	3.90
53	3.60	3.70	3.80	2.0	1.58	1.80	3.30	3.20	3.20
54	3.10	3.50	3.40	1.70	1.48	1.46	3.20	2.90	3.10
55	4.10	4.30	4.10	2.30	1.70	1.80	4.20	3.80	3.70
56	3.60	3.0	3.30	2.10	1.80	1.86	3.50	3.10	3.60
57	3.60	3.0	3.80	2.30	1.82	2.0	3.50	3.0	3.70
58	4.40	4.40	5.40	2.10	2.10	2.10	4.20	4.10	4.40
59	3.30	3.60	3.60	1.63	1.85	1.66	3.0	3.20	3.20
60	3.0	2.60	2.90	2.0	1.90	1.66	3.50	3.10	3.20
61	3.10	2.90	3.20	2.50	2.0	2.0	3.90	3.60	3.90
62	2.60	2.60	2.50	2.20	2.10	1.92	3.50	3.40	3.20
63	2.50	2.50	2.10	2.20	2.15	2.60	3.40	3.40	3.10
64	3.10	2.30	3.0	2.40	2.0	2.10	4.0	3.30	3.60
65	2.40	2.40	2.30	1.98	1.65	1.59	3.10	2.70	2.80
66	1.23	1.25	1.20						
Average	3.61	3.45	3.49	1.65	1.44	1.43	3.31	2.98	3.05

Division B.

Station	Horizontal, reflector type IV	V	VI	Vertical, reflector type IV	V	VI	45° reflector type IV	V	VI
1	1.50	1.45	1.37						
2	1.32	1.36	1.30						
3	1.42	1.40	1.35						
4	1.50	1.53	1.58						
5	2.30	2.50	2.40						
6	2.70	2.30	2.40						
7	2.60	2.60	2.50						
8	3.40	3.60	3.30						
9	2.80	2.80	2.80						
10	1.55	1.48	1.56						
11	2.00	1.94	2.00						
12	4.20	4.30	4.10	0.65	0.51	0.53	2.60	2.40	2.10
13	4.70	5.40	4.90	0.59	0.58	0.60	2.90	3.10	2.90
14	3.60	3.40	3.60	0.56	0.49	0.50	1.88	1.88	1.92

TABLE I.—(*Continued.*)

	Horizontal, reflector type			Vertical, reflector type			45°, reflector type		
Station	IV	V	VI	IV	V	VI	IV	V	VI
15	3.10	3.40	3.30	0.58	0.49	0.43	1.72	1.80	1.80
16	4.40	4.70	4.80	0.55	0.40	0.56	2.30	2.70	2.60
17	3.10	3.60	3.70	0.44	0.43	0.50	1.64	1.85	2.0
18	1.88	1.96	2.0	0.49	0.51	0.57	1.14	1.15	1.15
19	2.75	2.60	2.80	1.25	1.10	1.13	2.10	1.88	1.84
20	4.20	3.80	4.30	1.20	1.20	1.18	2.70	2.30	2.60
21	4.60	5.0	5.0	1.22	1.48	1.36	2.80	2.50	3.20
22	3.70	3.80	4.10	1.18	1.05	1.04	2.50	2.40	2.50
23	3.80	4.40	4.20	1.15	1.26	1.06	2.30	2.70	2.50
24	5.20	5.90	5.70	1.47	1.52	1.27	3.20	3.30	3.0
25	4.90	4.50	4.30	1.25	1.31	1.07	2.90	2.80	2.40
26	2.40	2.50	2.20						
27	2.70	2.80	2.75						
28	5.10	4.90	5.20	1.45	1.24	1.14	3.80	3.40	3.60
29	5.60	6.10	6.40	1.54	1.34	1.35	4.30	4.40	4.60
30	4.30	4.30	4.50	1.37	1.27	1.36	3.20	3.0	3.50
31	4.20	4.0	4.40	1.30	1.26	1.30	3.0	2.90	3.30
32	5.60	5.80	6.20	1.38	1.40	1.53	3.70	4.25	4.5
33	4.10	4.50	4.80	1.42	1.28	1.38	3.10	3.40	3.80
34	4.0	4.0	4.20	1.80	2.0	1.88	3.0	3.30	3.50
35	5.40	5.60	5.80	2.10	2.20	2.40	4.0	4.0	4.40
36	4.40	4.30	4.50	1.70	2.0	1.98	3.40	3.50	3.60
37	4.30	4.40	4.30	1.88	1.96	1.92	3.40	3.30	3.50
38	5.20	5.0	5.50	2.30	2.30	2.20	4.60	4.10	4.40
39	4.30	4.20	4.50	2.20	1.68	1.90	3.80	3.30	3.70
40	2.60	2.40	2.60						
41	1.80	1.81	1.92						
42	4.50	4.20	4.40	1.82	1.90	1.85	3.50	3.60	3.80
43	5.40	5.50	5.80	2.10	2.10	2.10	4.50	4.30	4.80
44	3.80	3.70	4.50	1.90	2.10	2.0	3.30	2.70	3.90
45	4.20	4.40	4.60	1.90	1.90	1.98	3.60	3.90	3.90
46	5.40	5.80	6.20	1.90	1.85	1.88	4.30	4.70	4.60
47	3.90	4.0	4.50	1.80	1.78	1.72	3.60	3.30	3.80
48	3.60	3.70	4.50	1.91	1.94	2.30	3.20	3.30	4.0
49	5.0	4.90	5.30	2.20	2.60	2.60	4.50	4.60	4.80
50	3.90	4.0	4.20	2.40	2.20	2.80	3.70	3.70	4.20
51	3.90	3.80	4.20	2.40	2.20	2.60	3.70	3.60	4.10
52	4.65	4.70	5.0	2.50	2.50	2.50	4.10	4.20	4.20
53	4.0	3.50	4.0	2.10	2.10	2.10	3.50	3.20	3.60
54	3.70	3.50	3.80	1.74	1.70	1.82	3.20	3.30	3.60
55	4.20	4.70	5.0	2.40	2.0	2.20	4.0	4.30	4.90
56	3.20	3.30	3.60	2.20	2.20	2.10	3.50	3.60	3.90
57	3.40	3.50	3.60	2.20	2.30	2.20	3.60	3.80	3.70
58	4.60	5.10	5.20	2.20	2.30	2.40	4.20	4.90	4.60

TABLE I.—(*Continued.*)

Station	Horizontal, reflector type IV	V	VI	Vertical, reflector type IV	V	VI	45°, reflector type IV	V	VI
59	3.90	3.90	4.30	1.78	1.81	2.40	3.20	3.50	4.0
60	2.50	2.50	3.0	2.0	2.20	2.40	3.30	3.70	3.80
61	3.20	3.20	3.80	2.30	2.60	2.40	4.40	4.20	4.6
62	2.30	2.60	2.50	2.10	2.30	2.40	3.20	3.0	3.40
63	2.50	2.40	2.60	2.60	2.80	2.10	3.60	3.80	3.40
64	3.10	2.90	3.0	2.30	2.40	2.40	4.0	4.0	4.0
65	2.30	2.40	2.40	2.0	2.0	2.10	3.10	3.00	3.10
66	1.14	1.16	1.42						
Average	3.80	3.70	4.20	1.675	1.68	1.71	3.30	3.31	3.49

TABLE II.

Compiled from Table I to show a comparison of the evenness of the illumination at the 122-cm. level given by the six types of reflector used.

Type of reflector	Mean variation of components: Vertical	Horizontal	45°	Percentage of mean variation of components: Vertical	Horizontal	45°
I	0.976	0.516	0.582	27.0	31.3	17.6
II	0.999	0.487	0.576	29.0	33.8	19.3
III	1.066	0.430	0.562	30.5	30.1	18.4
IV	1.21	0.498	0.601	31.8	29.7	18.2
V	1.10	0.539	0.628	29.8	32.1	19.0
VI	1.47	0.574	0.677	35.0	31.2	19.4

TABLE III.

Compiled from Table I to show the difference in the average values of the three components of illumination for the six types of reflector used.

Type of reflector	Difference between components: Vertical and horizontal	Vertical and 45°	45° and horizontal	Percentage of difference between components: Vertical and horizontal	Vertical and 45°	45° and horizontal
I	1.96	0.30	1.66	54.3	8.3	50.2
II	2.01	0.47	1.54	58.3	13.6	51.7
III	2.06	0.44	1.62	59.0	12.6	53.1
IV	2.125	0.50	1.625	55.9	13.2	49.2
V	2.02	0.39	1.63	54.6	10.5	49.2
VI	2.49	0.71	1.78	59.3	16.9	51.0

Figs. 2-5 are taken from the series of photographs showing the illumination effects produced by the six types of reflector used.[5] As was stated earlier in the paper, not so much use has been made of the photographic method of specification in this as in the former papers. In the former papers three photographs were given for each set of reflectors. One of these was taken from the south end of the room at a point 4 ft. (1.22 m.) from the

west wall. This photograph was taken so as to comprehend as much of the room as was possible in one view. It included the greater part of the ceiling, floor, and north wall, six of the fixtures and about one-half of the east wall. Another was taken to show the illumination effects in the west half of the room. This photograph represents the distribution of light and shade on the greater part of the west wall and adjacent ceiling and includes two of the fixtures. A third was taken primarily for showing the brightness measurements of all surfaces having a very high or very low brilliancy in the field of view of the observer. To have carried out this program in full in the present work would have required the insertion here of eighteen photographs. The amount of difference in the distribution of light and shade for the different reflectors was much too small to warrant this. It has in fact been deemed sufficient to include in this paper photographs for only the second and third of these positions and for only two of the sets of reflectors used,—the most opaque and the least opaque. The photographs for the second position are shown in Figs. 2 and 3; for the third, in 4 and 5. In representing the brightness measurements in Figs. 4 and 5, the spot measured is marked by a letter and the numerical value of the brightness measurement in candle-power per square inch is printed near by. The spots are lettered for convenience of reference in the tables of brightness measurements. The photographs were taken from a point directly behind the position of the observer as near to the south wall of the room as was possible; and although not all of the observer's field of view is covered by the brightness measurements made, owing to the narrow field of the camera as compared with the binocular field, still the order of magnitude of brightness differences present in the field of view is well represented by these measurements.

In Tables IV and V are given the brightness measurements of the room for the six sets of reflectors. These tables also include the letters identifying the measurements with the spots measured as shown in Figs. 4 and 5. The distribution of light and shade in the room was so similar for the different sets of reflectors that the spots measured have approximately the same location for each set of reflectors. Two sets of measurements were made of the brightness of the reflectors,—one with the opening of the

Fig. 2.—Showing the illumination of the west wall of the room, Reflector I.

Fig. 3.—Showing the illumination of the west wall of the room, Reflector VI.

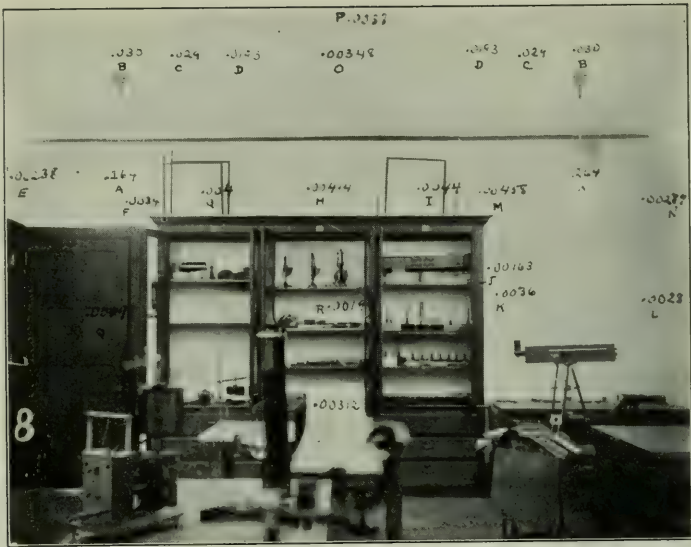


Fig. 4.—Showing the illumination effects in the north end of the room, Reflector I; and the brightness measurements of all surfaces having a very high or a very low brilliancy. This photograph was taken from a point directly behind the observer as near to the south wall of the room as was possible, and comprehends as much of the observer's field of view as could be included in the field of the camera.

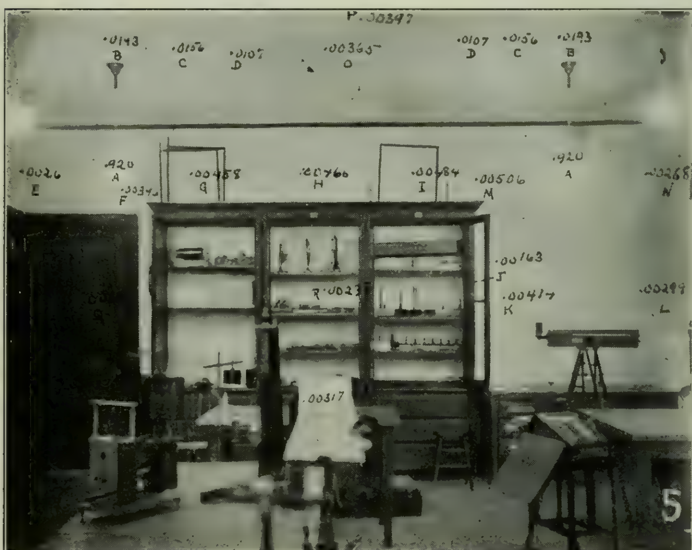


Fig. 5.—Showing the illumination effects in the north end of the room, Reflector VI; and the brightness measurements of all surfaces having a very high or a very low brilliancy. This photograph was taken from a point directly behind the observer as near to the south wall of the room as was possible, and comprehends as much of the observer's field of view as could be included in the field of the camera.

illuminometer close to the reflector and the other with the opening as nearly as possible in the position of the observer when making the test. In the former case the receiving arm was turned normal to the surface measured and the instrument was supported in such a position that the opening was about 4 in. (10.16 cm.) from this surface. The surfaces of some of the reflectors presented so much unevenness of brightness that overlapping measurements were made and an average taken. These average values are given in Table IV. In Table V is given the brightness of the reflectors as measured from the position of the observer. These measurements were taken of the reflectors at outlets A, B and C (Fig. 1) for each of the six installations. A comparison of these measurements will show that reflector B has in each case a higher value than reflector A, and C a higher value than B. Whether or not this can be wholly accounted for because the reflectors were not perfect diffusers we are not prepared to say. That is, the angle subtended by reflector A at the point of observation was less than that subtended by B, and by B less than that subtended by C; so that at the distance at which these reflectors was viewed approximately all of A occupied the field of the illuminometer in making the brightness match, while only the brighter central portions of B and C were comprehended in this field, still less of the duller periphery being included for C than for B.

In Tables VI and VII, are shown some prominent ratios of surface brightness for the six sets of reflectors. In compiling these ratios it has been considered important to make a comparative showing for the different types of reflectors (*a*) of the extremes of surface brightness and (*b*) of the relation of the brilliancy of objects in the surrounding field to the surface brightness at the point of work. Extremes of surface brightness are shown by giving the ratios between surfaces of the first, second, third, etc., order of brilliancy and the lowest order of brilliancy; and the comparison of the brilliancy of objects in the surrounding field to the brightness at the point of work by giving the ratios of the surfaces of the first, second, and third order of brilliancy to the brightness of the test card and the reading page in the working position.

TABLE IV.

Showing the brightness measurements in candlepower per square inch for the surfaces A, B, C, D, etc. (Figs. 4 and 5), the test card and reading page. These measurements were taken with the illuminometer close to the surface measured and with its receiving arm normal to this surface.

Surface measured	Reflector type I.	Reflector type II	Reflector type III	Reflector type IV	Reflector type V	Reflector type VI
A........	0.264	0.361	0.392	0.614	0.848	0.920
B........	0.030	0.01985	0.024	0.0101	0.0137	0.0193
C........	0.029	0.021	0.021	0.0123	0.0166	0.0156
D........	0.0193	0.0106	0.0075	0.0070	0.00767	0.0107
E........	0.00238	0.00246	0.00229	0.00282	0.00255	0.0026
F........	0.0034	0.00394	0.0034	0.00396	0.00396	0.00396
G........	0.0040	0.00392	0.0042	0.00497	0.00418	0.00458
H	0.00414	0.00396	0.0044	0.00506	0.0043	0.00466
I	0.0044	0.00402	0.00453	0.00528	0.0042	0.00484
J	0.00163	0.0011	0.00128	0.00141	0.00123	0.00163
K	0.0036	0.00387	0.00414	0.0044	0.00425	0.00414
L........	0.0023	0.00224	0.00282	0.00299	0.00273	0.00299
M	0.00458	0.00405	0.00484	0.0052	0.00427	0.00506
N........	0.00277	0.00216	0.00216	0.00334	0.00268	0.00268
O........	0.00348	0.00299	0.00462	0.00361	0.00361	0.00365
P	0.0037	0.00312	0.00506	0.00409	0.0037	0.00397
Q........	0.00097	0.00083	0.00106	0.00099	0.000924	0.00106
R........	0.00199	0.0029	0.00207	0.00220	0.00246	0.00238
Test card.	0.00312	0.00308	0.00308	0.00317	0.00312	0.00317
Reading page horizontal..	0.00528	0.00497	0.00506	0.0052	0.00484	0.00484
Reading page 45° position..	0.00352	0.00348	0.00352	0.00348	0.00334	0.00339

TABLE V.

Showing the brightness measurements in candlepower per square inch of the reflectors used when the measurements are made from the position occupied by the observer during the test. In these measurements the receiving arm of the illuminometer was placed as nearly as possible in the position of the observer's eye during the test, and was pointed at the reflector. The position of the reflector in each case is shown by the letters A, B and C in Fig. 1.

Position of reflector	Reflector type I	Reflector type II	Reflector type III	Reflector type IV	Reflector type V	Reflector type VI
A........	0.119	0.156	0.180	0.2325	0.327	0.382
B........	0.1755	0.1913	0.2025	0.2535	0.338	0.405
C........	0.2025	0.338	0.397	0.544	0.722	0.830

Supplementary to Tables IV, VI and VII we have computed for the six types of reflector the mean variation of the several brightness values from their average values. While important from the standpoint of showing the variations from the mean for the different types of reflector, such a comparison is, however, probably not so important from the standpoint of the eye as are the comparisons given in Tables IV to VII. That is, from the standpoint of the effect on the eye it is probably more important to give a representation of the brightness of individual surfaces, more especially of surfaces showing extremes of brightness, than it is to give the mean variation from the average brightness of all the surfaces. In order to make possible the comparison with and without the reflector and the spot above the reflector, the table is made to show separately the mean variation of the following measurements: (*a*) for all: (*b*) for all but the reflector; and (*c*) for all but the reflector and the spot above the reflector. Results are given in Table VIII.

As was stated earlier in the paper the effect of a harmful installation on the ability of the eye to maintain its efficiency for a period of work varies with the position of the observer in the room. In the former work the tests were made at four positions, one in which six fixtures were in the field of view; one in which four were in the field of view; one in which two were in the field of view; and one in which none was in the field of view. This variation of the position in which the observation is made accomplishes two purposes: (1) it gives us a more representative idea of the difference of the effect on the eye of the six types of lighting used; and (2) it shows the effect of varying the number of surfaces in the field of view showing brightness differences, particularly the number of primary sources. So far we have been able to conduct the tests for the reflectors used in this work at only one of these positions, namely, the one with six reflectors in the field of view.[6] Later we expect to repeat the tests for at least a part of these reflectors at the other three positions.

The results for the effect on the eye are given in Table IX.[7] The values given in this table are averaged in each case from the results of 6 three-hour tests and are typical of the results obtained for all of our observers. In order to show the repro-

TABLE VI.*

Ratios showing the extremes of surface brightness for the six types of reflectors used.

Division A.

Ratio	Reflector type I	Reflector type II	Reflector type III
Lightest to darkest	0.264 /0.00097 = 272.0	0.361 /0.00083 = 435.0	0.392 /0.00106 = 370.0
2nd lightest to darkest	0.030 /0.00097 = 31.0	0.021 /0.00083 = 25.3	0.024 /0.00106 = 22.6
3rd lightest to darkest	0.029 /0.00097 = 29.9	0.01985/0.00083 = 23.9	0.021 /0.00106 = 19.8
4th lightest to darkest	0.0193 /0.00097 = 20.0	0.0106 /0.00083 = 12.8	0.0075 /0.00106 = 7.08
5th lightest to darkest	0.00458/0.00097 = 4.72	0.00405/0.00083 = 4.88	0.00506/0.00106 = 4.77
6th lightest to darkest	0.0044 /0.00097 = 4.54	0.00402/0.00083 = 4.84	0.00484/0.00106 = 4.57
7th lightest to darkest	0.00414/0.00097 = 4.27	0.00396/0.00083 = 4.77	0.00462/0.00106 = 4.36
8th lightest to darkest	0.0040 /0.00097 = 4.12	0.00394/0.00083 = 4.75	0.00453/0.00106 = 4.27
9th lightest to darkest	0.0037 /0.00097 = 3.81	0.00392/0.00083 = 4.72	0.0044 /0.00106 = 4.15
10th lightest to darkest	0.0036 /0.00097 = 3.71	0.00387/0.00083 = 4.66	0.0042 /0.00106 = 3.96
11th lightest to darkest	0.00348/0.00097 = 3.59	0.00312/0.00083 = 3.76	0.00414/0.00106 = 3.91
12th lightest to darkest	0.0034 /0.00097 = 3.51	0.00299/0.00083 = 3.60	0.0034 /0.00106 = 3.21
13th lightest to darkest	0.00277/0.00097 = 2.86	0.0029 /0.00083 = 3.49	0.00282/0.00106 = 2.66
14th lightest to darkest	0.00238/0.00097 = 2.45	0.00246/0.00083 = 2.96	0.00229/0.00106 = 2.16
15th lightest to darkest	0.0023 /0.00097 = 2.37	0.00224/0.00083 = 2.70	0.00216/0.00106 = 2.04
16th lightest to darkest	0.00199/0.00097 = 2.05	0.00216/0.00083 = 2.60	0.00207/0.00106 = 1.95
17th lightest to darkest	0.00163/0.00097 = 1.68	0.0011 /0.00083 = 1.33	0.00128/0.00106 = 1.21

TABLE VI.

Division B.

Ratio	Reflector type IV	Reflector type V	Reflector type VI
Lightest to darkest	0.614 /0.00099 = 620.0	0.848 /0.000924 = 918.0	0.92 /0.00106 = 868.0
2nd lightest to darkest.........	0.0123 /0.00099 = 12.4	0.0166 /0.000924 = 18.0	0.0193 /0.00106 = 18.2
3rd lightest to darkest	0.0101 /0.00099 = 10.2	0.0137 /0.000924 = 14.8	0.0156 /0.00106 = 14.7
4th lightest to darkest	0.007 /0.00099 = 7.70	0.00767/0.000924 = 8.30	0.0107 /0.00106 = 10.1
5th lightest to darkest	0.00528/0.00099 = 5.33	0.0043 /0.000924 = 4.65	0.00506/0.00106 = 4.77
6th lightest to darkest	0.0052 /0.00099 = 5.25	0.00427/0.000924 = 4.62	0.00484/0.00106 = 4.57
7th lightest to darkest	0.00506/0.00099 = 5.11	0.00425/0.000924 = 4.60	0.00466/0.00106 = 4.40
8th lightest to darkest	0.00497/0.00099 = 5.02	0.0042 /0.000924 = 4.55	0.00458/0.00106 = 4.32
9th lightest to darkest	0.0044 /0.00099 = 4.44	0.00418/0.000924 = 4.52	0.00414/0.00106 = 3.91
10th lightest to darkest	0.00409/0.00099 = 4.13	0.00396/0.000924 = 4.29	0.00397/0.00106 = 3.74
11th lightest to darkest	0.00396/0.00099 = 4.0	0.0037 /0.000924 = 4.0	0.00396/0.00106 = 3.73
12th lightest to darkest	0.00361/0.00099 = 3.65	0.00361/0.000924 = 3.91	0.00365/0.00106 = 3.44
13th lightest to darkest	0.00334/0.00099 = 3.37	0.00273/0.000924 = 2.95	0.00299/0.00106 = 2.82
14th lightest to darkest	0.00299/0.00099 = 3.02	0.00268/0.000924 = 2.90	0.00268/0.00106 = 2.53
15th lightest to darkest	0.00282/0.00099 = 2.85	0.00255/0.000924 = 2.76	0.0026 /0.00106 = 2.45
16th lightest to darkest	0.0022 /0.00099 = 2.22	0.00246/0.000924 = 2.66	0.00238/0.00106 = 2.24
17th lightest to darkest	0.00141/0.00099 = 1.42	0.00123/0.000924 = 1.33	0.00163/0.00106 = 1.54

* It will be noted in Tables IV and VI that while the reflectors grade in brightness from I to VI in an unbroken series, the ratio lightest to darkest for Reflector III is less than for Reflector II, and for Reflector VI than for Reflector V. This in all probability is because of a difference in distribution effects given by these reflectors due to a difference in power to diffuse the light. That is, while the brightest spots (the reflectors) grade in an unbroken series, the darkest spots do not.

TABLE VII.

Ratios showing the relation of the brilliancy of objects in the surrounding field to the surface brightness at the point of work for the six types of reflector used.

Division A.

Ratio	Reflector type I	Reflector type II	Reflector type III
Lightest to test card	0.264 /0.00312 = 84.7	0.361 /0.00308 = 117.2	0.392 /0.00317 = 123.7
Lightest to reading page	0.264 /0.00352 = 75.0	0.361 /0.00348 = 103.8	0.392 /0.00348 = 112.6
2nd lightest to test card.........	0.030 /0.00312 = 9.61	0.021 /0.00308 = 6.8	0.024 /0.00317 = 7.57
2nd lightest to reading page	0.030 /0.00352 = 8.5	0.021 /0.00348 = 6.3	0.024 /0.00348 = 6.9
3rd lightest to test card	0.029 /0.00312 = 9.29	0.01985/0.00308 = 6.46	0.021 /0.00317 = 6.62
3rd lightest so reading page	0.029 /0.00352 = 8.2	0.01985/0.00348 = 5.70	0.021 /0.00348 = 6.03

Division B.

Ratio	Reflector type IV	Reflector type V	Reflector type VI
Lightest to test card	0.614 /0.00317 = 193.7	0.848 /0.00312 = 272.0	0.92 /0.00317 = 290.2
Lightest to reading page	0.614 /0.00348 = 176.4	0.848 /0.00334 = 248.0	0.92 /0.00339 = 271.0
2nd lightest to test card	0.0123/0.00317 = 3.88	0.0166 /0.00312 = 5.32	0.0193/0.00317 = 6.09
2nd lightest to reading page	0.0123/0.00348 = 3.53	0.0166 /0.00334 = 4.97	0.0193/0.00339 = 5.7
3rd lightest to test card	0.0101/0.00317 = 3.19	0.00137/0.00312 = 4.39	0.0156/0.00317 = 4.92
3rd lightest to reading page	0.0101/0.00348 = 2.90	0.00137/0.00334 = 4.1	0.0156/0.00339 = 4.6

ducibility of the results obtained and that the variations produced by the changes in lighting effects are much greater than the variations in the test itself, subject to all the variable factors which may influence it, the mean variation from the average result has been computed in each case. The value of this in per cent. is given in column 15.[8]

TABLE VIII.

Compiled from Table IV to show the mean variations in surface brightness for the six types of reflector used.

Division A.

Measurements considered	Mean variation for the three reflectors — Reflector type I	II	III	Percentage of mean variation for the three reflectors — Reflector type I	II	III
All	0.02885	0.0373	0.0405	134.8	148.0	148.4
All but the reflector	0.00667	0.00412	0.00411	93.2	75.3	70.3
All but the reflector and the spots above the reflector	0.000917	0.000884	0.0012	29.5	29.7	35.8

Division B.

Measurements considered	Mean variation for the three reflectors — Reflector type IV	V	VI	Percentage of mean variation for the three reflectors — Reflector type IV	V	VI
All	0.06494	0.08852	0.09597	168.0	170.8	170.5
All but the reflector	0.0020	0.00274	0.00342	42.4	56.0	62.0
All but the reflector and the spots above the reflector	0.00111	0.000964	0.00104	30.9	30.0	30.2

In Chart 1 a graphic representation is made of the results of this table. In constructing this chart, the total length of the test period is plotted along the abscissa, and the ratio of the time the test object is seen clear to the time it is seen blurred in the three-minute records before and after work is plotted along the ordinate. Each one of the large squares along the abscissa represents one hour of the test period, and along the ordinate an integer of the ratio.

So far in all our work we have shown for the sake of completeness of representation the gradation of surface brightness in three ways.—(1) Brightness measurements of prominent surfaces have been made. (2) Ratios have been given between surfaces of the first, second, third, etc., order of brilliancy and surfaces of the lowest order of brilliancy; and between sur-

TABLE IX.

Showing the tendency of the six types of reflector to cause loss of visual efficiency, or power to sustain clear seeing.

Reflector type	Watts	Volts	Intensity foot-candles. Horizontal	Vertical	45°	Time	Maximal distance at which test object can be seen clear	Working distance	Total time clear	Total time blurred	Total time clear ÷ total time blurred	Ratios reduced to common standard	Loss of efficiency expressed in percentage drop in ratio	Mean variation (per cent.)
I	800	111.0	4.1	1.14	2.7	9 A.M.	80.2	62.2	138.5	41.5	3.34	3.5	—	—
						12 M.	80.0	62.2	133.0	47.0	2.83	2.97	15	0.86
II	800	110.0	3.7	1.13	2.6	9 A.M.	80.0	64.0	139.0	41.0	3.39	3.5	—	—
						12 M.	79.5	64.0	115.0	65.0	1.77	1.82	48	0.77
III	800	107.5	4.2	1.16	2.6	9 A.M.	80.0	64.0	145.0	35.0	4.14	3.5	—	—
						12 M.	79.5	64.0	118.0	62.0	1.9	1.60	54	0.70
IV	800	105.5	3.8	1.15	2.5	9 A.M.	79.5	63.6	145.0	35.0	4.14	3.5	—	—
						12 M.	79.0	63.6	112.0	68.0	1.65	1.39	60	2.0
V	800	105.5	3.7	1.15	2.6	9 A.M.	79.5	63.6	140.1	39.9	3.51	3.5	—	—
						12 M.	78.5	63.6	91.0	89.0	1.02	1.017	71	0.86
VI	800	107.5	4.2	1.16	2.7	9 A.M.	79.5	63.6	141.0	39.0	3.62	3.5	—	—
						12 M.	78.5	63.6	89.0	91.0	0.978	0.945	73	1.0

TABLE X

Showing a comparison of the tendency of the six types of reflector used to cause loss of efficiency and to produce ocular discomfort. The tendency to produce discomfort is estimated by the time required for just noticeable discomfort to be set up.

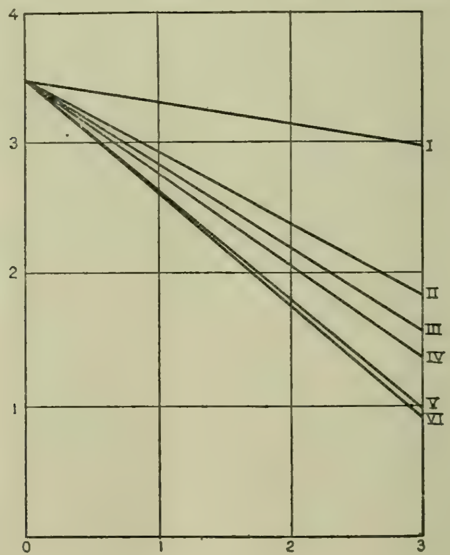
Reflectors	Volts	Foot-candles			Per cent. loss of efficiency	Mean variation (Per cent.)	Time limen of discomfort in seconds (not reading)	Mean variation (Per cent.)	Change produced by changing type of reflector (Per cent.)	Time limen of discomfort in seconds (reading)	Mean variation (Per cent.)	Change produced by changing type of reflector (Per cent.)
		Horizontal	Vertical	45°								
Type I..	111	4.1	1.14	2.7	15	0.86	80	1.1		25	1.6	
Type II..	110	3.7	1.13	2.6	48	0.77	45	1.5	43.8	17	1.5	32.0
Type III.	107.5	4.2	1.16	2.6	54	0.70	34	1.8	24.4	14	2.1	17.7
Type IV.	105.5	3.8	1.15	2.5	60	2.0	21	[illegible].4	38.2	10	2.0	28.6
Type V..	105.5	3.7	1.15	2.6	71	0.86	17	2.[illegible]	19.0	8	2.3	20.0
Type VI.	107.5	4.2	1.16	2.7	73	1.0	15	2.7	11.8	6.5	3.0	18.8

faces of the first, second and third order of brilliancy and the brightness at the point of work. And (3) the mean variation from the average and the percentage of mean variation have been shown. In the consideration of these specifications, a number of

CHART I.

Showing the tendency of the six types of reflectors to cause loss of visual efficiency, or power to sustain clear seeing. Ratio time clear to time blurred is plotted against length of test period.

Reflector	Volts	Foot-candles Horizontal	Vertical	45°
Type I	111	4.1	1.14	2.7
Type II	110	3.7	1.13	2.6
Type III	107.5	4.2	1.16	2.6
Type IV	105.5	3.8	1.15	2.5
Type V	105.5	3.7	1.15	2.6
Type VI	107.5	4.2	1.16	2.7



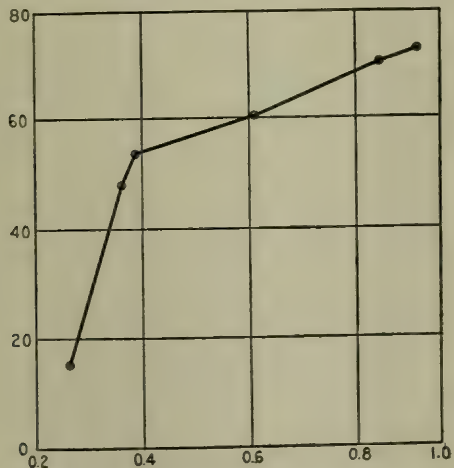
single items might be selected as of possible significance in relation to the effect on the eye. Among these may be mentioned the order of magnitude of the highest brilliancies; the average brilliancy; the ratio of the highest to the lowest order of brilliancy; the ratio of the highest order of brilliancy to the average bril-

liancy; the ratio of the average to the lowest order of brilliancy; the ratio of the highest order of brilliancy to the brilliancy at the point of work, (brightness of test card and reading page); etc. In order to see which of these correlate most closely with the results of the test for tendency to cause loss of efficiency,

CHART II.

Showing the tendency of the six types of reflectors to cause loss of visual efficiency or power to sustain clear seeing. Percentage drop in ratio time clear to time blurred is plotted against brightness of reflector in candlepower per square inch.

		Foot-candles			
Reflector	Volts	Horizontal	Vertical	45°	Cp. per sq. in.
Type I	111	4.1	1.14	2.7	0.264
Type II	110	3.7	1.13	2.6	0.361
Type III	107.5	4.2	1.16	2.6	0.392
Type IV	105.5	3.8	1.15	2.5	0.614
Type V	105.5	3.7	1.15	2.6	0.848
Type VI	107.5	4.2	1.16	2.7	0.920



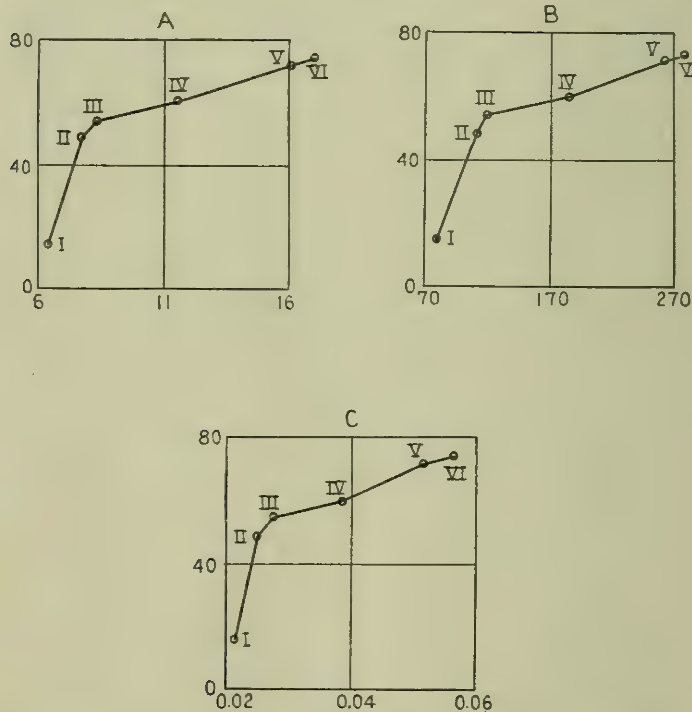
curves are constructed in which some of these features are plotted against the results of the test. These curves are given in Charts II to IV. In Chart II per cent. loss of efficiency is plotted against the highest order of brilliancy, namely, the brightness of the reflectors. In Chart III and IV are grouped the remainder of the curves.

Another method of evaluating the results of our test was briefly

treated of in a discussion of Mr. Cravath's paper by one of the writers. (The TRANSACTIONS, 1914, IX, pp. 1051-1053.) In this method the ratio of the time seen clear to the total time of the observation is taken as the measure of the ability of the eye

CHART III.

Showing the tendency of the six types of reflectors to cause loss of visual efficiency or power to sustain clear seeing. In curve A percentage drop in ratio time clear to time blurred is plotted against ratio of average brightness to brightness at point of work; in B, against ratio of lightest surface to brightness at point of work; and in C, against average brightness.

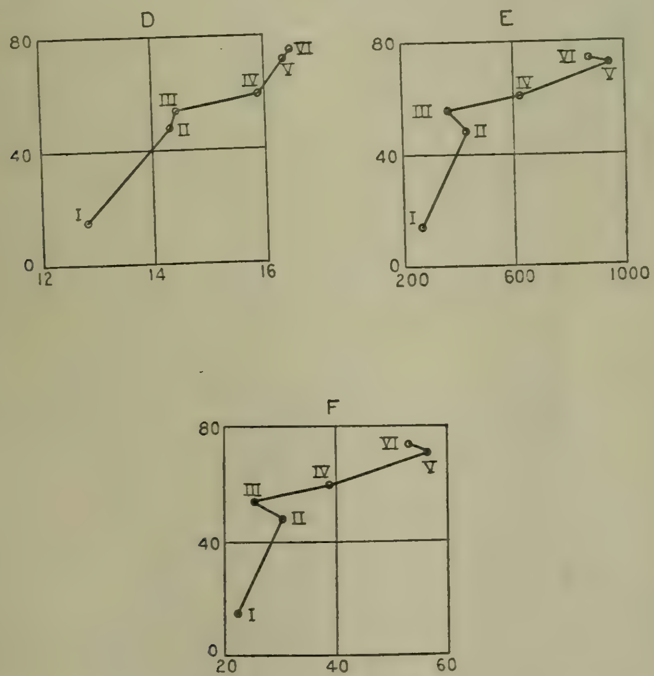


to sustain clear seeing at the time the test is taken. For the sake of comparing this method of evaluation with the one we have used in the rest of the paper, Charts V and VI have been constructed. In Chart V length of test period is plotted along the abscissa, and the ratio of time clear to total time of observation is plotted along the ordinate. In plotting these lines, one of the larger squares

along the abscissa represents one hour of the test period, and along the ordinate, 0.1 ratio, time seen clear to the total time of the observation. That is, in this method of treating the results, since the ratios, or the quantities to be plotted along the abscissa, are much smaller than they are in the former method, the scale

CHART IV.

Showing the tendency of the six types of reflector to cause loss of visual efficiency or power to sustain clear seeing. In curve D percentage drop in ratio time clear to time blurred is plotted against ratio of lightest surface to average brightness; in E, against ratio of lightest surface to darkest surface; and in F, against ratio of average brightness to darkest surface.



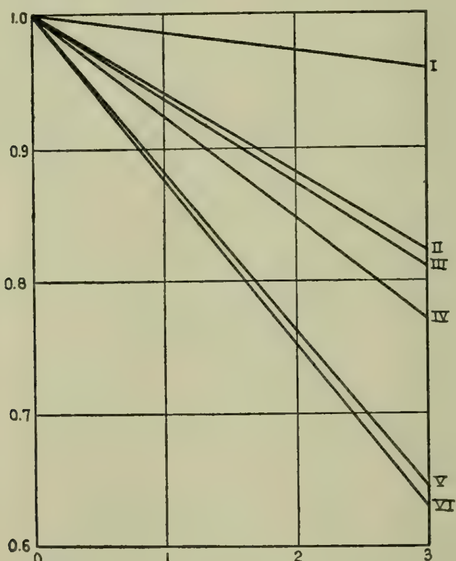
has been multiplied by 10 for convenience of representation. In order that the lines may all start at a common point, the initial ratios are reduced to 1 as a common standard. In Chart VI, per cent. loss of efficiency as evaluated by this method is plotted against intrinsic brilliancy of reflector. As before, intrinsic brilliancy of reflector is plotted along the abscissa, and per cent.

loss of efficiency along the ordinate. A comparison of these results with the former will show the same order of rating of the reflectors but a slight change in the position in the scale given to some of the reflectors. For the purpose of discovering what is

CHART V.

Showing the tendency of the six types of reflectors to cause loss of visual efficiency or power to sustain clear seeing. Ratio of time clear to total time of observation is plotted against length of test period.

		Foot-candles		
Reflector	Volts	Horizontal	Vertical	45°
Type I	111	4.1	1.14	2.7
Type II	110	3.7	1.13	2.6
Type III	107.5	4.2	1.16	2.6
Type IV	105.5	3.8	1.15	2.5
Type V	105.5	3.7	1.15	2.6
Type VI	107.5	4.2	1.16	2.7



the best way of treating the results of the tests, several methods have been employed. Up to and including the present paper, however, only three of them have been given in print: ratio of time clear to time blurred, ratio of time clear to total time of

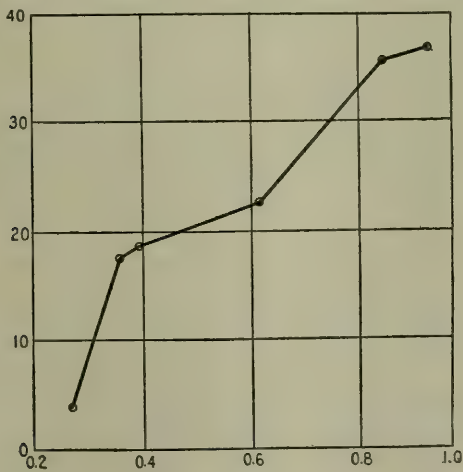
observation, and the per cent. of drop in the ratio time clear to time blurred. An ultimate decision with regard to what is the best method of treatment of the results can come, we believe, only with the consideration of a larger number of cases.

The work was concluded by determining for the six types of

CHART VI.

Showing the tendency of the six types of reflectors to cause loss of visual efficiency or power to sustain clear seeing. Percentage drop in ratio time clear to total time of observation is plotted against brightness of reflector in candlepower per square inch.

Reflector	Volts	Foot-candles Horizontal	Vertical	45°	Cp. per sq. in.
Type I	111	4.1	1.14	2.7	0.264
Type II	110	3.7	1.13	2.6	0.361
Type III	107.5	4.2	1.16	2.6	0.392
Type IV	105.5	3.8	1.15	2.5	0.614
Type V	105.5	3.7	1.15	2.6	0.848
Type VI	107.5	4.2	1.16	2.7	0.920



installations the relative tendencies to produce ocular discomfort. As before, two cases were made of this determination,—one when the eye was at rest, the other when it was at work. For a description of how the determination is made, and a discussion of the method that is used, see the TRANSACTIONS of the I. E .S., 1913, VIII, pp. 54-58; and 1915, X, pp. 496-501. Space will be taken here only for presentation of the results. These are given

in Table X. In this table are given also, for the sake of comparison, results expressing the tendency of the six types of reflectors to cause loss of ability to sustain clear seeing.

APPENDIX.

The reflectors used in this work were supplied by the Holophane Works of the General Electric Co., and are opal glass of light, medium, and heavy densities. They are all of the bowl type and of the same size, 8 in. Reflector I is a pressed Sudan toned brown; reflector II, a blown white glass, toned brown (experimental); reflector III, a pressed Sudan; reflector IV, a pressed Druid; reflector V, a blown Veluria; and reflector VI, a blown white glass (experimental). Reflectors I, III, IV and V are commercial products, but II and VI are special, inserted in the series to give gradations in density. As was stated in the text these reflectors presented considerable unevenness of surface brightness. This was especially true of the pressed reflectors, which are smooth on the inside and grooved on the outside. The glass in these grooves being thinner than in the spaces between, a very uneven surface brilliancy is given to the reflector. Further, reflector IV, because of its imperfect diffusion, was quite a little brighter in the center, at the location of the filament, than at the top and bottom. In determining the brightness of these reflectors, overlapping readings were taken and an average obtained.

NOTES.

[1] The truth of this should be obvious to any methodological critic. It is in fact the logical corollary of the application of a new test to a new field. Until a range of application is made which is reasonably representative of the work for which the test is designed to be used, a complete description of the test itself, including a statement of the factors which may influence its results and full directions how to use it, cannot possibly be given without more presumption than we care to exercise. While an attempt to do this might afford a certain amount of specious satisfaction to the practicing engineer, it would be superficial and incomplete and calculated to produce trouble in the work of others. When in the opinion of the authors a sufficient range of work has been covered, a separate paper will again be devoted to the test method itself in which data collected from all the work will be submitted, and the adaptability and application of the method to different kinds of work will be discussed. It is clear, we think, to anyone who has had experience in developing and applying a new test that this can be done more safely and effectively at the close of a section of the work which is sufficiently comprehensive to be representative of the accomplishment of the test, than at its beginning or while the work is yet in progress. In this later paper data will be submitted also on four types of test devised by us to detect changes in the functional condition of the retina as the result of working under different conditions of lighting.

Two points keep coming up, however, with a degree of persistence which may

justify a somewhat detailed discussion at this time. The first pertains to the sensitivity of the test to factors extraneous to the conditions that are being tested. The point was briefly discussed in the original paper on the test and again in the two succeeding papers. It was brought out more especially in Mr. Cravath's paper and in the discussions following it. Among other things it was shown in this paper that by purposely varying these factors in some extreme way they could be made to influence the results of the test. The more crucial point was not shown however; namely, that they operate against the usefulness of the test when the work is done under the conditions that ordinarily obtain in a well conducted experiment; nor does the paper contain any evidence that Mr. Cravath thinks this is the case. In our own work a different plan has been pursued with regard to this point. Instead of trying to find out what effects could be produced by means of procedures that would not be permitted in making a test, every care has been taken from the beginning to eliminate or hold as constant as possible all extraneous factors which might influence the general and muscular efficiency of the eye, and to check up the effectiveness of this control by carefully determining the mean variation in the results for each set of lighting conditions. This we have considered to be the most direct and feasible plan of conducting the work. In any event, it is obvious that there is no need of futile speculation concerning the possibilities of influence of these factors, nor of any indefiniteness either in the discussion or investigation of the point, so long as the actual value of the influence can be measured by determining the mean variation and its relative value be estimated by comparing the mean variation with the variations produced by changing the conditions to be tested. That is, a measure of the absolute and relative value of these factors is readily available and this measure has been carefully used at every step in the work. We need scarcely to point out that it is a well recognized principle of experimentation in comparative work such as we are doing that as long as the mean variation is safely within the experimental variation, the method is considered satisfactory for the purpose for which it is being used.

In this connection it may not be out of place to give here a more detailed account than has yet been given of the method that has been used in selecting and training observers. Care is exercised in the first place to choose one who has shown a satisfactory degree of precision in threshold and equality judgments in other optical work in the laboratory, and whose clinical record shows no uncorrected defects of consequence The observer is then practised on the three minute record under a lighting condition selected and maintained for the purpose, until a satisfactory degree of reproducibility is shown. These records are usually run in series of five with a twenty minute rest interval between each record. So far we have not published the results of an observer who has not been able to attain a reproducibility in the time seen clear of 1 per cent. for a series of five records in these preliminary experiments, although this degree of precision is unnecessary unless the observer is being trained for work in which there are very small differences in the conditions to be tested. Since these records are run with no change in the lighting conditions and with rest intervals to prevent general or optical fatigue, they serve primarily as a training in making the judgment and as a check on the precision of the judgment. In the second stage of preparation the observer makes a number of three hour tests with records before and after work for two or more lighting installations, and the mean variation of the results from the average is determined. Again, if a sufficiently small mean variation is not shown where there has been no change in the lighting conditions, the observer is not allowed to take part in the actual work of testing. This last mean variation is the final preliminary check upon all the factors that may vary under the control imposed,—lack of reproducibility in the judgment, variable physical and mental fatigue, etc. The final check is had in the course of the work itself. That is, a number of tests are made for each lighting condition of the series to be investigated, and the mean variation is determined for each and compared with the variations that are produced by the changes in the conditions to be tested, to find out to what extent these variations may be ascribed to the changes made and to what extent to the normal variation of the test. How much larger is the variation which is produced by changing the lighting conditions than is the normal variation for each condition may

be seen by comparing Columns 14 and 15 of Table IX. In the work of the preceding papers the excess of the experimental variation over the mean variation was much greater still as might be expected from the greater differences that were present in the lighting conditions tested. For example, in five three hour tests for the indirect system for Position I (see this TRANSACTIONS 1915, X, pp. 413-426) the mean variation in per cent. was 1.1; for the semi-indirect system it was 1.4; and for the direct system, 1.2; while the percentage drop in the ratio from beginning to close of work for these systems was respectively, 8.5, 72.3, and 80.9. Similar citations may be made for the other conditions tested. When one compares in these cases the mean variation with the magnitude of change of ratio produced by changing the lighting system, it becomes obvious how unnecessary has been the concern about the influence of extraneous factors in case of the work that has as yet been done. In fact, the mean variation has been so safely within the experimental variation that the writers have not felt it necessary heretofore to make the numerical comparison in print. It is so well recognized as an experimental principle that the experimental variation shall safely exceed the mean variation that it has been their custom to give the comparison only when there exists some grounds for doubt. Heretofore, we have, as a general case, been working with conditions that produced a large difference in results.

As bearing on another phase of the question of reproducibility, namely, where a long interval has elapsed between two series of tests, we may cite one example where two series were taken under the same lighting conditions a year apart, and the variation in the average per cent. loss of efficiency was only 0.3. In this case a favorable lighting system was used, the initial ratios were closely the same, and the control in general good, although no especial care was taken to make it so more than what is ordinarily exercised. It is not presented, however, as a typical instance. It happens to be the only case of which we have a record, where a long interval has elapsed between two tests.

Moreover, there is nothing in the nature of the test other than its superior sensitivity that should make it more susceptible to the influence of extraneous factors than any other test of acuity. The principle of the test will be remembered from the earlier papers. It is merely the conventional acuity test subjected to certain features of standardization for the sake of greater reproducibility, and made into an endurance test to give it additional sensitivity. The older test had not been found to be sufficiently sensitive to fatigue conditions to warrant adoption in our work. This test is in fact not meant to be a fatigue test. It was designed to test the dioptric condition of the eye, and may be used with more or less success as a test of how far a given lighting condition is conducive to clear seeing with *a maximum of momentary effort*; but it has not the essentials of a fatigue test nor of its converse, the ease with which clearness of seeing is attained,—which is what is needed primarily for the selection of lighting conditions for the greater part of the work that we are ordinarily called upon o do. Almost if not quite as good results, for example, may be gotten with it after work as before, when there is every other reason to believe the eye has suffered considerable depression in functional power. The reason for this is obvious. Although greatly fatigued, the eye can, under the spur of the test, be whipped up to give almost if not quite as good results as the non-fatigued organ when only a momentary effort is required. (See Column 8, Table IX, and former papers.) If fatigued, however, it can not be expected to sustain this extra effort for a period of time. The demonstration of this fact led early in our work to the introduction of the time element into the test. The principle involved is not a new one. It is merely the application of a very old and well known one to the work of testing for optical fatigue. If, for example, a sensitive test is wanted for the detection of fatigue in a muscle, as good results can not be expected if the test requires only a momentary effort on the part of the muscle as would be attained if the endurance of the muscle were taken into account. For our purpose, therefore, the old acuity test has been made into an endurance test, in which the fatigue or loss of functional efficiency of the eye is measured by its power to sustain clear seeing for a period of time. As such it should and does show a sensitivity for detecting fatigue far beyond what can be attained by the older and more established test when it is used

for that purpose. And being a test which is more sensitive to functional changes in the eye, it doubtless does show in some proportion to its greater sensitivity more effect of the indirect as well as of the direct factors that influence acuity; but since the indirect factors can be subjected to control, while the direct factors are varied, there is in proportion to the sensitivity of the test and the control exercised a gain for the purpose for which the test is used. That this gain is great is shown in all our work by a comparison of the size of the mean variation with that of the variation produced by the change in the conditions to be tested.

The second point we wish to discuss here refers to the part played in our experiments by a factor known among psychophysicists as the error of expectation. The belief that there is a need to take account of this error in sense judgments arises from the difficulty in keeping the observer in ignorance of the test material and of a certain amount of the experimental procedure. In our experiments there are just two points on which the observer has knowledge: namely, the test object and the lighting conditions or system under which the work is done. All the rest is kept concealed from him unless the experimenter should in turn serve as observer in which case his results are checked up by those of observers who have not served as experimenter. We will consider this factor first in relation to the test object. The observer knows what the test object is (the letters li in 8 point type) and is told to record, for example, when the dot is seen separate from the vertical line in the letter i. The question at issue then is whether proper account is taken in our experimental procedure of the influence of expectation on this judgment. The question can be discussed the most comprehensively perhaps by first considering rather broadly the status and development of experimental method with regard to this factor. As we have already intimated, the probable influence of expectation is an inherent difficulty in all sense judgments,—photometric, acuity, threshold, etc. That it can not be entirely eliminated is, we think, generally conceded as axiomatic. Psychophysicists have, therefore, turned their attention to attempts to compensate for it, and a need has been felt to do this in most cases only when the work requires that the determination be made with a great deal of precision. Different methods may be employed for this purpose all of which are more or less open to question. The one most frequently used perhaps, is the method of ascending and descending series. From a consideration of this method an idea may be had in a general way of all the methods of its class. Rather than to eliminate or even to lessen the operation of the factor, the purpose of this method is to control its direction and to plan the experiment in opposing series, so as to compensate for its influence in the final result. That is, in making a threshold determination, for example, the series in one case is begun below the threshold, and the observer is told that the stimulus will be increased until the threshold is reached; in the other case the procedure is reversed. For the final result an average is taken of the values so determined on the assumption that expectation in the two cases will influence the determination by equal amounts in opposite directions. Much has been said in the literature of psychophysics with regard to whether this method accomplishes what it is intended to accomplish, and more might be said; but it is immaterial for our purpose whether it does or not, for it is obvious that it could not be applied to our 3 minute records, for here the image to be judged rises to the threshold of discrimination independently of the control of either the observer or the experimenter. The individual judgments, therefore, could not be arranged in opposing series for the purpose of compensation. An entirely different type of method is to use an objective check on the judgment of the observer, and by this means endeavor to weed out from the results the influence of subjective factors. We tried for several months to devise a means of changing the stimulus in such a way that an objective check could be had on the registration of the observer without sacrificing the principle of the test. Such a change, however, could not be made in the test object which did not at the same time permit the eye to relax its strain at the instant of change, which it is obvious destroys the very feature which gives the test its superior sensitivity. The attempt to get an objective check, however, was made more for the sake of offsetting possible criticism than it was because of any belief that it was necessary for the purpose for which the test has so far been used;

for, as we have already stated, a determination of the mean variation for the 3 minute record, each one of which consists of a number of separate judgments, had shown us that the influence of expectation as a source of variable error is of negligible consequence. That is, the mean variation is the measure of the aggregate effect of all the variable factors including expectation, if indeed it be a source of error in the case under consideration, and it was found to be too small as compared with the variations produced by the changes in the conditions tested to be the cause for any concern for the purpose of the work. Moreover, it will be remembered that a knowledge of the test object is given to the observer as one of three changes that were made in the conventional acuity test to minimize very obvious sources of variable error, among which were memory and expectation, and to give a greater reproducibility to the judgment. We can do no better probably than quote from the original discussion. "Visual acuity tests of the Snellen type, especially when used in work in which it is required to make successive tests on the same person, are open to the following objections. (*a*) The judgment is in terms of recognition. A letter may be recognized when it is not seen clearly. In any judgment based on the recognition of even a single letter, memory plays an important role. It is, so far as the writer knows, impossible to standardize this memory factor and to obtain results strictly in terms of acuteness of vision. (*b*) The test card is made up of quite a long series of letters. As the test progresses the letters are memorized more and more completely. It is practically impossible to eliminate this progressive error when a number of successive judgments have to be made as is the case before a final result is reached in any single visual acuity test and as is especially the case when a number of successive tests have to be given to the same person, which happens in much of the work involved in the solution of the problem here proposed .... (*c*) The Snellen series contains quite a large number of letters. The eye is found to fatigue and vision to blur before the series is completed. This introduces an error which it is practically impossible to render constant." All of the above errors were eliminated, or at least minimized, in the tests finally adopted by us by changing the type of judgment and by adopting a simple test object, made up of only two characters, the letters li in 8 pt. type. In this test the observer's acuity of vision is determined by the distance at which he can just clearly distinguish the two test objects. In practise it has come to be a matter of distinguishing whether or not the dot is separated from the vertical line in the image of the letter i. The results are thus rendered directly in terms of acuity of vision and the progressive errors due to memory and expectation are minimized. In this regard the significance of the change in the type of judgment from recognition to the judgment of the separateness of two simple objects, *e. g.*, the dot and the line in the letter i, should not be overlooked. When the criterion is recognition and the task set for the observer is merely to identify the test object with its name or some memory of it from past experience, as is the case in the old form of the test, memory and expectation play their maximum role. Any extraneous clue or a partial discrimination of the object may in fact serve as a basis for all that is required in the judgment. When, however, the task set for the observer is a different one and he is required to judge the presence or absence of a space between the dot and line in the letter i, the role of these factors is reduced to a minimum, and the task is narrowed down to the judgment of a space threshold, one of the simplest and most reproducible types of sense judgment. In short then, a knowledge of the test object is given to the observer as a part of the modification of the conventional acuity test to minimize the effect of variable factors, among which memory and expectation play the chief role. And that it has accomplished its purpose is abundantly attested by a comparison of the size of the mean variation given by the test so revised as compared with that given by the older form. We may add that the letter l is used in connection with the letter i for two reasons. (1) A steadier fixation is given than can be attained by so small an object as the letter i; and (2) a standard is afforded (an unbroken vertical line) in terms of which to judge the separateness of the dot from the vertical line in the letter i.

The only other way in which expectation can come into the experiment through knowledge on the part of the observer is, as we have already stated, through an

awareness of the conditions or lighting system tested. The observer can not work for three hours under a given lighting installation without being more or less aware that the same installation is being used as was used before, or a different one. Moreover, we do not see how this unfortunate factor can be completely eliminated unless imbeciles be used for observers. We wish to point out, however, that there is no greater liability to harmful influences from this factor in our test than in the older acuity test or any other that could be applied to the same type of work. We grant that, in any test that could be used, if observers of strong commercial or other bias should in two isolated trials get better results for one type of lighting than another, there might be grounds for suspecting that prejudiced observations were made: but if each condition were tested a number of times, as has been the case in all of our work, and a small mean variation were obtained for each series of tests, the result would look much more like the response of an organism to a constant set of conditions in obedience to physiological law than it would like a voluntary reproduction guided by prejudice, however strong and constant that prejudice might be. Here again the size of the mean variation is the check upon the validity of the results, for it is obvious, we think, even to a novice, that records taken at intervals of from one to five days could not show a close reproduction if the fidelity of the registration were in any way interfered with by the wishes or prejudice of the observer. Furthermore, it is only fair to say that it would be difficult to find a group of observers freer from a direct interest in lighting conditions or a knowledge of their significance than is the group from which the greater number of our observers are selected.

[2] These factors are the evenness of illumination, the evenness of surface brightness, the diffuseness of light, the angle at which the light falls on the work, intensity, and quality.

[3] The problem of installing is probably not the same for the inverted translucent as for the inverted opaque reflectors. In the latter case the height should be so adjusted as to give as nearly as possible an even distribution of surface brightness on the ceiling, and evenness of illumination on the working plane. In case the inverted translucent reflectors, however, if the distance from the ceiling is made great enough in all cases to produce these effects, it may throw the bright reflectors too low in the field of vision for the highest efficiency and the greatest comfort to the eye. In this regard the opaque reflectors have the advantage that it is always easier with them to get the brightest surface in the room out of the zone of most harmful influence in the field of vision. In later work we expect to conduct a series of experiments with the above reflectors in which the height from the ceiling is the factor varied.

[4] The track along which the test card was moved was parallel to the east and west walls of the room. When taking the test the observer faced the north wall in such a position that when the eyes were in the primary position the lines of regard were parallel with the east and west walls of the room, and approximately normal to the north and south walls. That is, the head was erect and held in such a position that the objects in the room, reflectors, etc., fell as symmetrically as was possible within the field of view. During the three hours of reading which intervened between the two three minute records, the observer moved just far enough back from the upright supporting the mouth board to give room for the book to be held, and to permit of a comfortable reading position. Care was taken to have the eyes sustain as nearly as was possible the same general relations to the objects of the room as were sustained when the three minute records were taken. This could be done either by holding the head erect, etc., or by tilting slightly backward in the swivel chair used by the observer and allowing the head to relax a compensating amount. So far as the direct optical effects are concerned, it would seem to be immaterial which of these positions is chosen, so long as approximately the same field of vision is obtained. The latter is usually preferred by the observer as causing less general fatigue. When taking this position, the book is elevated and held at ap-

proximately an angle of 45° (a little nearer to the vertical than this perhaps). The brightness measurements of the book at this angle and in the horizontal are not taken, however, so much because of this as to give the brightness of the book in two fixed representative positions at the point of work. Care is taken to have print of uniform size and distinctness for use with the three systems and to have a page which gives a comparatively small amount of specular reflection. Uniformity in these regards can usually be secured by using numbers of the same journal.

[5] It should not be needful to mention that the recording apparatus is screened from the observer's view while the test is being made. Before photographing, the screen was removed and the apparatus regrouped.

[6] This is the test station shown in Fig. 1, and of the four used in the former work is the one nearest to the south wall of the room.

[7] As has been stated in our former papers, in the consideration of the effect of a given lighting situation on the ability of the eye to hold its efficiency for a period of work, the age of the observer and the condition of his eyes should be taken into account. All of the observers who have been employed by us in this work have been under 28 years of age. Following is the clinic report of the eyes of the observer whose results are given in Tables IX and X, made by Dr. Wm. Campbell Posey of Philadelphia.

Observer R.

With glasses.—Vision of right eye = 20/25. Far muscle test = 0 ½ esophoria.
Vision of left eye = 20/20. Near muscle test = orthophoria.
Ophthalmoscopic examination.—Right eye = mixed astigmatism, ½ diopter.
Left eye = hyperopic astigmatism, 1½ diopters.
External condition.—Adduction good; eyes slightly divergent under cover; cornea clear; pupils, 2½ mm.; irides respond equally and freely to light, accommodation, and convergence stimuli.
Glasses worn during test.—Right eye = —S., 0.50 D.; —C., 0.37D., x 160°
Left eye = —C., 0.50 D., x 180°

Early in our work the problem arose whether the three minute records before and after work should be taken in the same room in which the work was done or in a separate room reserved solely for that purpose. To test this point, work was done in both ways. It was found that the effects of smaller differences in lighting conditions could be detected when both the three minute records and the work were done under the lighting conditions to be tested. That is, the total test procedure, which includes both the three minute records and the reading, is more sensitive when it is all done under the conditions to be tested, than when a part of it is done under these conditions and a part in a separate room. Since the method is more sensitive when the whole procedure is conducted under the lighting conditions to be tested, we can see no reason why even the purist should demand that a part of it be done under the conditions to be tested and a part somewhere else, so long as the results are recognized to be the consequence both of the three minute records and of the reading. Our purpose, it will be remembered, has been to get a sensitive means of detecting the relative tendencies of different lighting conditions to cause a loss in the power of the eye to sustain its ability to see clearly; and the method is more sensitive when the three minute records, also, are made under the conditions to be tested. This, we may say, is our chief reason for the practice. A justification, we believe, is not logically needed. Moreover, the method so conducted is just as amenable to control and to checks upon its reproducibility, as if it were used in the less sensitive form. It is, in fact, considerably more amenable to control, for if a separate room were used for the three minute records, very great care would have to be exercised to see that it was always illuminated with exactly the same intensity of light that was used in the room in which the reading was done. If the illumination were not accurately the same, a period of adaptation would have to be allowed before the three minute record could be made, which, in case of the record taken after work, would give the eye opportunity to recover from the fatigue induced by

the work. It is obvious that a great deal of difficulty would be encountered in accurately maintaining this control; and, if it were not so maintained, an error of considerable consequence would be introduced into the work. In getting control not only the illumination of the test object must be taken into account, but the brightness of the whole field of vision with its complex distribution of light and shade, for this conditions the state of adaptation of the paracentral and peripheral portions of the retina which in turn exerts an influence on the part of the retina that receives the image of the test object. It may be added also that adaptation effects in the paracentral and peripheral portions of the retina are stronger and more rapid than in the central portions.

In connection with the fact that the three minute records add sensitivity to the method when they are also taken under the conditions to be tested, we may say that we are now working on a short method in which three minute records with proper rest intervals are used. This test is rougher and less sensitive than the longer method, but if it can be made satisfactory, it might be more adaptable to practical work.

[8] It will be noted in this table that there is very little variation in the value of the initial ratios. We noted in each of our preceding papers and again in our discussion of Mr. Cravath's paper that the sensitivity of the test varies with the ratio of the working distance of the test object from the observer to the acuity distance. After considerable investigation of the point, we adopted, as a standard to be attained approximately, a ratio of distances that would give for the initial record a ratio of time clear to time blurred of 3.5. As might be expected, it is impossible to get this ratio of 3.5 exactly from any single ratio of working distance to acuity distance that can be determined in advance of the actual record. But with care a close approximation may be attained, and since the loss of efficiency is judged from the amount this ratio is changed from the beginning to the close of work, and not from the ratio itself, the failure to obtain it does not affect a comparison of the favorableness of different lighting conditions for the eye, any more than is represented by its effect on the sensitivity of the test. In short, the variations in this ratio from test to test form merely one of the group of variable factors, the check upon the effect of which on the results of the test, is the size of the mean variation; and, so long as this mean variation is safely within the amount of variation produced by changing the conditions to be tested, the control may be considered as satisfactory for the purpose of the work that is being done. That is, when this check is properly exercised, the influence of a variation in this ratio can not possibly be mistaken for the effect of the condition which is being tested. However, in the course of the determination of what value of initial ratio should be used, considerable study was made of the effect of varying the ratio. While space will not permit us to quote largely from these results here, still an idea may be given in the space at our command, of the order of magnitude of the effect that is produced. That is, we will take three cases including a range of differences amply great to cover what is ever apt to occur in actual work. In the first, the initial ratios were 2. and 3. (difference, 1); in the second, 2.67 and 5 (difference, 2.33); and in the third, 1.93 and 7.57 (difference, 5.64). The difference in the percentage loss of efficiency for the first case was 1.4; in the second, 2; and in the third, 1.7. The effect shown in these cases, it will be observed, is about of the same order as the normal mean variation of the test.

[9] In order to make a fair comparison between the drop in ratio time clear to time blurred caused by working under a given lighting condition and the mean variation of the drop, the percentage drop and the percentage mean variation are both estimated in the above table, also in the citation made in Note 8, p. 1129, on the same base, 3.5. If this comparison had not been wanted especially to show that the mean variation produced by changing the type of reflector, it would have been more in accord with custom perhaps to have expressed the mean variation as a percent. of the mean value of the drop. Computed in this way the value of the mean variation for Reflectors I-VI would have been in order 5.6 per cent., 1.6 per cent., 1.3 per cent., 3.3 per cent., 1.2 per cent., 1.4 per cent.; and for the citation in Note 8, they

would have been for the indirect system 4.5 per cent., for the semi-indirect system 0.7 per cent., and for the direct system 0.5 per cent. This method of estimating the mean variation gives, it will be noted, the largest per cent. variation for the most favorable lighting condition because the drop in ratio, the base on which the percentage is estimated, is the smallest for this condition. The actual variation we have found as a rule is, as might be expected, the least for the most favorable condition.

DISCUSSION.

MR. J. R. CRAVATH: Dr. Ferree calls his test a test "loss of efficiency of the eye." I think the term "eye-fatigue" is much briefer and more expressive. The work reported in a previous paper of Dr. Ferree covered conditions rather widely varied. The paper we have before us now covers conditions which come within fairly narrow limits of visible source brightness. The results have been especially interesting to me as a member of the Committee on Glare because we have, during the past year, attempted to formulate or to express certain limits of good practise which are least conducive to glare. In ordinary interior illumination, we state in our report, which is soon to be published, that contrasts of brightness of adjacent surfaces (I mean by adjacent surfaces, those which are adjacent within the visual field) should not be over a ratio of one to two hundred, and preferably not over one to one hundred. That ratio was taken as the result of an examination of a good deal of data, some of

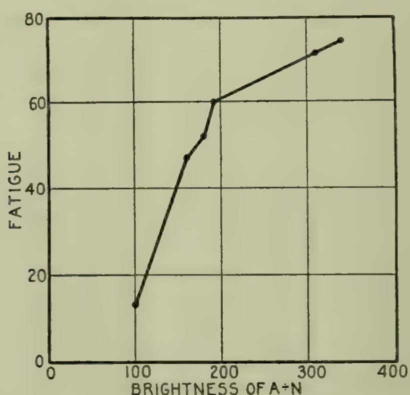


Fig. 1.

them in previous papers of Dr. Ferree. It was therefore of considerable interest to me to see how the results in the present paper

conform with these limits and in order to do that, I have taken the ratio between the brightest spot, which of course, is the reflector, and the point N on the room photograph a little to the right of the reflector, and plotted a curve, Fig. 1, corresponding to Chart II but, instead of using the brightness of the reflector, I have used the ratio of the brightness of the reflector to the darkest point along side of it; that is the point N. The ratios of A to N under 200 seem to give notably less fatigue than those above 1 to 200, which would confirm the judgment of our committee as well as the previous results obtained from various sources.

Dr. J. W. Schereschewsky: I want to congratulate Dr. Ferree on the extreme care which is evident in all these series of tests to obtain small mean deviations and secure reproducibility of results. I wish to call attention, however, to one factor, which in all probability, will have considerable effect on all tests which involve muscular action and that is the question of weather conditions. It is plain to all who have read this paper that tests of this kind such as Dr. Ferree has here published are labors requiring a great deal of care in arranging and carrying out, and it seems to me that we ought, by all means, in working tests of this character, to insure, as much as possible that the work shall not be thrown away because of great variations in the results due to extraneous factors. Now it seems to me that tests of this kind ought never to be conducted in very hot weather. The effect of high degrees of heat and humidity is to reduce the endurance of muscle. That seems to be plain from Prof. F. Lee's experiments which were done in the investigations of the New York Ventilation Commission, in which it was found that sections of muscles removed from animals which had been subjected to high degrees of temperature and humidity furnished on the average 40 to 50 per cent. less contractions than muscles of animals which had not been so exposed. Therefore, it seems to me that persons who conduct tests of this kind in very hot weather would find a great loss of efficiency of the eye simply from exposure to weather conditions; so in the future, when we are endeavoring to corroborate the results of these tests by similar tests, we must take the precaution never to undertake such tests except when the atmospheric conditions are distinctly comfortable.

MR. T. W. ROLPH: The data given in this paper are very valuable to us who have lighting systems to design.

I should like to call attention to the ratio between the brilliancy of the ceiling and brilliancy of the reflectors as obtained in these measurements. Reflectors 4 and 5 are typical reflectors of the class which is most commonly used to-day for semi-indirect lighting, and in this particular installation, which does not represent all installations, but is possibly a typical installation, the ratio between the brilliancy of the reflector and the brilliancy of the ceiling is one to fifty, and with reflector 5, one to sixty-one, taking the brightest point on the ceiling. Those are the reflectors which show the greatest eye fatigue, and this shows us how far we will still have to go in reducing intrinsic brilliancy in order to get semi-indirect lighting systems which are correct from the engineering standpoint. Now, reflector No. 3 is a commercial reflector which is being used to a certain extent for semi-indirect lighting. It is denser glass and it is harder to sell than reflectors 4 and 5, so that we who are working for better lighting in the commercial field have that to contend with. Reflector 3 shows a ratio between the brilliancy of the ceiling and the brilliancy of the reflector of one to sixteen. The densest reflector tested has a ratio of one to nine. Three years ago, in a paper on the "Engineering Principles of Semi-Indirect Lighting," I argued that, from the engineering standpoint, the brilliancy of the reflector in an installation should be approximately the same as the brilliancy of the ceiling. That was not particularly from the standpoint of eye protection, but from the standpoint of obtaining the maximum diffusion of illumination, arguing that if we are going to sacrifice the efficiency of direct lighting by installing semi-indirect systems, we should try to get the maximum engineering value of the semi-indirect systems, by obtaining maximum diffusion, and that this would be obtained when the brilliancy of the bowl is approximately the same as the brilliancy of the ceiling. This paper indicates that to obtain good eye-protection in semi-indirect lighting, we should work to very much denser glassware or very much lower brilliancy of reflector bowl than is generally practised to-day. Even a ratio of one to nine, where the reflector is nine times as bright as the ceiling, shows a considerable degree of eye fatigue.

There is one point I should like to bring out in connection with the measurement of the intrinsic brilliancy of these reflectors, and that is merely a suggestion that possibly a good way to obtain the intrinsic brilliance of a reflector of this character would be to take the candlepower as determined on the photometer, and the area of the reflector as determined on a drawing board, and thus find the candlepower per square inch, rather than to take luminosity measurements of the reflector at various points and average them. I believe it would be more accurate to take the candlepower of the reflector and simply divide it by the projected area in the direction of view.

Mr. J. R. Cravath: This question of what shall be taken as the criterion of brightness is something that Dr. Ferree evidently is not sure of, and I don't think any of the rest of us are—I mean, what particular contrast shall be taken. Mr. Rolph has just mentioned the contrast of the brightness of the reflector with the brightness of the ceiling above. Dr. Ferree has given us results showing the highest brilliancy, that is, the brilliancy of the reflector, and the average brilliancy, and the ratio of the highest to the lowest and the ratio of the highest to the average, the ratio of the average to the lowest and the ratio of the highest to the brilliancy of the point of work. There is such a great deal to be said in favor of his objection that, possibly, in a case where the subject is working continuously on desk work or reading that the ratio of the brightest object in view to the work, that is, to the paper on which the eye is working, should be the criterion; because in that case, the brightest objects in view appear simply on the edge of the retina most of the time, while the paper is on the center; but for most practical purposes, I think perhaps the criterion adopted by the Committee on Glare of the ratio between the nearest adjacent surfaces would answer all practical purposes for the present. I also want to express the debt that I feel the practical men of the society owe to the investigators who bring out this kind of data; it is exactly what we need to make progress in our work.

Dr. C. E. Ferree (In reply): I suggested in a former paper that, theoretically considered, better results should be gotten with the semi-indirect reflector of such a density as to give a surface brilliancy equal to that of the ceiling spot than are obtained with

the totally indirect reflector. That is, if the reflector is made of the same brightness as the ceiling spot, the same light flux can be obtained with a lower intrinsic brilliancy of the brightest surface than if the light all comes from the ceiling spot because of the increase of luminous area. This is in agreement, I believe, with the general tenor of Mr. Rolph's discussion. Unfortunately, however, I have not yet been able to obtain reflectors of sufficient density to test the point directly. However, in the work that we have done, an increase in the density of the reflector, so far as we have been able to carry the increase with the reflectors supplied us for the purpose, has been accompanied by a consistent improvement in the effect on the eye. There is one thing to be claimed, however, in favor of the indirect reflector when all is said and done. It is easier with it to remove the brightest spot in the field of vision from the zone of harmful influence to the eye, especially in rooms of the height ordinarily found in dwelling houses, because with this type of reflector the brightest spot is always on the ceiling. With reference to the effect of position or rather height of the brightest spot in the field of vision, it may not be out of place to anticipate here in slight measure the content of a future paper. In the work of the present paper the reflectors were installed 30 inches from the ceiling. This is in accord with general practise for the installation of totally indirect reflectors in rooms of the height of our test room and is considered to give a favorable distribution of light and shade on the ceiling and a comparatively even distribution of light on the working plane. So installed, however, the brightest spot (the reflector) is dropped well into the field of view, especially at the outlets most removed from the observer. The question arises, therefore, whether semi-indirect reflectors should be installed according to the principles of indirect lighting, direct lighting, or whether some compromise should be made between the two. We have begun, therefore, a series of tests in which the distance of the reflector from the ceiling is varied. So far we have been able to finish the comparison for the reflectors of least and greatest density at distances of 30 in. and 15 in. from the ceiling. The 15-in. distance gave quite considerable improvement in the effect on the eye for the reflector of least density, but not nearly so much for the reflector of greatest density. This result suggests that a more careful

study should be made of the method of installing semi-indirect reflectors differing in density. It would seem that the denser they are the more nearly they can afford to be installed as indirect reflectors and the less dense they are the more nearly they should be installed as direct reflectors so far as eye effects of the kind revealed by our tests are concerned.

I have no doubt that Dr. Schereschewsky is right about the probable effect of excessive temperature on the results of tests such as ours. I am very frank to confess, however, that I never do anything on a hot day if I can help it; and I certainly would not conduct a test when the temperature is excessively high. Through the greater part of the year the temperature of our test room is kept within a small variation by thermostat control. If it is necessary to work on warm days electric fans are used; but on no account are tests ever made on hot, humid days. In fact nearly as much care has been taken, I should say, to secure uniformity in temperature control in our work as has been taken to secure a uniform control of illumination and brightness effects. I am confident, therefore, that our results so far have not suffered from temperature as a variable factor. If I may digress here for a moment, I should like to say, with no reference whatever to Dr. Schereschewsky, whose discussions I have always found to be most considerate and intelligently liberal in tone, that I am becoming somewhat tired of the subject of extraneous factors. To speculate about their probable influence may be of considerable cultural value to those who have heretofore thought little about the subject, but there is no need to worry about their influence or to stand in the way of reasonable progress when a gauge on the amount of their influence may be and has been had at every step in the work. In this latter connection I refer to a careful determination of the mean or average variation. If this is done as it has been done at every step in the training of the observer; if moreover it is done for each condition tested and a comparison made of its amount with the amount of variation produced by changing the condition tested; exact knowledge is had in every case whether or not the results obtained are significant. The subject of gauging the influence of variable factors is too old and has been too carefully worked out to justify the raising in any

scientific body of as much elementary discussion as has been raised with regard to it in this Society. The procedure in general is very simple and straightforward. Train the observer on every feature of the test method with careful attention to the size of the mean variation. In the actual work determine the mean variation for each set of conditions tested and compare it with the variation produced by changing the conditions to be tested. If its sum for any two sets of conditions is not less than the difference between the average results obtained for the two conditions these results, it is usually considered, can not be claimed as significant. I have spent months, for example, in the training of an observer on the different features of the test method, only to discard him at the end of that time because a sufficient degree of precision of record could not be obtained under a constant set of lighting conditions. Those who have shown in such a course of training an unsatisfactory degree of precision usually reveal on examination, I may say, some uncorrected optical defect. Muscle imbalance more often than any other seems to have been the defect in the cases which have so far given us trouble. This may mean that the extrinsic more often than the intrinsic muscles are the cause of a variable performance on the part of the eye in tasks such as we have set for it in our tests, but it is also probable that the occurrence is due to a considerable extent to the fact that in ophthalmological practise small defects in muscle balance are more often left uncorrected than are, for example, refraction defects.

In concluding my comments on this point I think I may be justified in mentioning that I have spent a greater number of years than I like to recall in trying to get control of the variable factors that influence the response of the eye; and that I have added considerably to the precision of its performance under experimental conditions, I can only call upon my published work to testify. It is not likely, therefore, that in the course of developing a new test I would show such a degree of incaution with regard to the most elementary and well-known principles of experimentation as was made the subject of serious and somewhat pretentious inquiry in the discussions of the paper preceding the present one, and in the discussions aroused by Mr. Cravath's paper.

I am glad Mr. Cravath has given us still another way of plotting the results of the tests against brightness effects. It has not occurred to me, however, to attach any especial importance as a separate factor to the ratio of the brilliancy of the brightest area to that of its immediately contiguous surroundings. There are, for example, only two possible effects that I could conceive to be due to this relation, neither one of which would seem to me to warrant making of it a separate factor. (1) It would enhance by physiological induction in some proportion to the difference in physical brightness, the brightness of the sensation aroused by the reflector and thus increase its power to set up muscular strain by distracting the eye from the adjustment needed for the work in hand. So considered, however, its action would merely be that of an auxiliary factor, supplementary to the actual brightness of the reflector. As such it is of course of a great deal of importance, greater perhaps, for example, that the relation of lightest to darkest surface, as brightnesses are graded in a room ordinarily well illuminated. In short it would seem to me that the point of reference in determining the relations that are of importance to the eye is the brightness at the point of work. Any extreme deviation above or below this brightness, especially above, or anything that would make these deviations conspicuous to vision would seem to me to be of prime importance. I would, therefore, consider it an important addition to our present method of specifying brightness effects to give more detailed measurements, so far as is practicable, of the surroundings immediately contiguous to the brightest spot, because the effect of that spot upon sensation is to an important degree dependent upon the immediate surroundings; but I would by no means be willing to make these measurements and that of the brightest spot the sole specification of brightness effects, as Mr. Cravath suggests might be sufficient for our present needs. Moreover, it must not be overlooked in this connection that a curve plotted on a basis of the ratio of A, brightness of the reflector, to N for the different conditions tested must give a curve very similar to that plotted on the basis of the brightness of the reflectors alone, for N does not vary greatly from a constant value for the six sets of reflectors we have used. Obviously, therefore, cognizance should be taken of this fact before too much general importance is attri-

buted to this ratio as a separate factor from the shape of the curve plotted by Mr. Cravath for this particular set of conditions. (2) There might, it is conceivable, be some unknown effect on the retina which directly depresses its functional power or indirectly disturbs the adjustment of the eye. I have, however, already tested quite extensively the tendency of different lighting conditions to depress the functional power of the retina for as much as ten hours of continuous work and have found reason to believe that very little indeed of our results for the tests for loss of efficiency could be ascribed to a depression of retinal function. There are four ways, I may say, in which a change in the functional activity of the retina may be manifested: (a) a change in sensitivity to color and brightness; (b) a change in lag or the time required for the sensation to reach its maximum; (c) a change in the susceptibility to fatigue or exhaustion, measured by rate of exhaustion; and (d) a change in the power of recovery, measured by rate of recovery. All of these points were covered in the tests mentioned above. Short of such an investigation a complete record can not be given of the functional state of the retina at any time or as the result of any condition or set of conditions to which it may be subjected. But when such tests have been conducted for a period of exposure of the eye to the conditions tested more than three times as long as was used in the tests for loss of efficiency, it would seem reasonable to conclude that the results of this latter test could not be ascribed to any considerable extent to a depression of retinal activity.

Mr. Cravath has always quarreled with me over what the test should be called and perhaps on good grounds. If "fatigue" is a more palatable term to the engineer than "loss of efficiency," I am quite willing that the test shall be called a fatigue test. I have in fact called it that part of the time myself. My reason for calling it something else in the beginning was primarily one of profession. Among men in physiological and psychological optics the term fatigue as applied to the eye has been, since the days of Fechner and Helmholtz, a technical term connotating a retinal condition. It was chiefly to avoid the chance of confusion with the narrower usage of fatigue that I chose the broader term loss of efficiency as a brief designation of what is really tested, namely, the loss in the power of the eye to sustain clear seeing.

DISCUSSION.*

MR. J. R. CRAVATH (Communicated): To my mind this work of Dr. Ferree's as reported in his paper and at previous conventions of the Society is of great and far reaching importance. Before we can deal intelligently with problems of illumination we must have methods of measuring the effect of different kinds of illumination upon the eye. Methods devised previous to the Ferree test were generally admitted to be unsatisfactory in that they took no account of the fatiguing effect of continuous work under given conditions. It will be noted that Prof. Ferree refers to his test as one to determine the "efficiency of the eye" while I have used† the term "eye fatigue" instead of "eye efficiency." It is of course the privilege of the originator of a method to apply whatever descriptive terms he wishes to the method, but it appears to me that "eye fatigue" expresses more nearly what is really brought out by the Ferree test and conveys a more definite meaning to the majority of those not intimately in touch with this kind of work. In connection with Dr. Ferree's results on moving pictures, it has been my observation that some moving picture shows are so well equipped and operated that the pictures are free from flicker and vibration and there is very little conscious eyestrain, while others using worn out films and making no effort to get steady light or to prevent vibration of the machine produce pictures which are very trying to the eyes. I should suppose that a picture show in a suburb like Bryn Mawr would be obliged to maintain a high standard of service as compared with many others throughout the country and that probably Dr. Ferree's results on moving picture shows might show fatigue rather less than the average.

DR. NELSON M. BLACK (Communicated): The Illuminating Engineering Society is to be congratulated that the carrying out of a series of investigations of such magnitude has been under the direction of such scientific and painstaking observers as the

* The following discussion while it applies somewhat to the foregoing paper refers more particularly to a paper entitled "Further Experiments on the Efficiency of the Eye Under Different Conditions of Lighting" by C. E. Ferree and G. Rand, which appears on pp. 448-501, vol. X, of the TRANSACTIONS of the I. E. S.

† Cravath, J. R., Some Experiments with the Ferree Test for Eye Fatigue; TRANS. I. E. S., vol. IX, p. 1033.

authors. The mass of data is almost appalling but the deductions made are clear, concise and very important.

The comparison of the loss in efficiency of the eye when the observer is in the different positions in the room and the eyes are subjected to the varying degrees of surface brightness of objects within the field of view with the three different sources of illumination is most interesting and instructive. The deductions from the series of experiments, that the scale of brightness magnitude and the illumination effects for the indirect system is very close to what the eye is adapted to stand without loss of efficiency, is most important and could be taken as a standard in determining the amount of surface brightness of objects allowable in lighting installations of any character.

Another important point is that the position of the observer in the room does not seem to materially affect ocular efficiency under the indirect system, especially when one considers that the illumination of the working surface remains approximately the same with all systems.

The result of the experiments conducted with the eye shades with dark and light lining are in accord with those obtained by Ives and Luckiesh in their investigations of the influence of the direction of light on ocular comfort, *i. e.*, that the most pleasant landscape to view seemed to be one in which there was a preponderance of brightness in the sky, with a foreground showing various degrees of light and shade.

The authors state "it is a question whether any practical good can accrue to the practise of lighting from a knowledge of just what part of the visual apparatus it is that falls off in function as the result of an unfavorable condition of lighting." It would seem that this is of prime importance.

The result of the investigation of the effect of the three systems of lighting upon the factors mentioned as involved in clear seeing, *i. e.*, the sensitivity of the eye to colored and white light and the ability to make fine discriminations and accommodation, will be awaited with interest.

DR. WALTER B. LANCASTER (Communicated): Is it not increasingly clear as each successive paper in this series appears that Prof. Ferree and Dr. Rand are more successfully solv-

ing these problems they have undertaken than any investigators so far in the field? It is not to be expected that we should agree with all their interpretations of their results. The important thing is that their methods seem to give consistent and reproducible results in their hands.

I am glad to see that they have apparently abandoned their view that the first of the three tests is a test of the efficiency of the accommodation and now speak of it as "a test of the ability of the eye to hold its efficiency for a period of work," and as "a test for loss of efficiency for clear seeing;" that is they do not commit themselves to any theory of how the test works. As a result of the few trials I have made of the test on myself and half a dozen other observers, I am convinced that the accommodation has nothing to do with the blurring but that it is a retinal affair and depends chiefly on steadiness of fixation—immobility of the eye, and that in turn on attention, to a by-no-means-negligible degree. However, this is a minor matter, the important question being, does it give results when applied to problems of the hygiene of the eye.

Their observation on eye-shades with light and dark linings are very convincing and important (Table XXV, page 500), since they agree so well with what was to be expected theoretically but contradict the popular view. This popular view will die hard like the popular view of the importance of shielding the eyes by wearing glasses impervious to ultra-violet light.

The results of tests on moving pictures are also important since, while every one knew that bad moving pictures are very fatiguing, few suspected that good moving pictures were so harmless as shown by chart VIII.

The results of specular versus diffuse reflection (Chart V, page 485), do not show as great a falling off in efficiency under specular reflection as might have been expected. Doubtless this is due to the fact that so small a percentage of the total illumination of the test object was specular under the conditions of this particular experiment. The angle at which the light falls on the work is more important than these figures would imply. This is strikingly shown by some facts to be found in Table XX, *viz.*, even after three hours work under diffuse illumination the ratio

time clear to time blurred (3.18) is the same as the ratio at the very beginning of work under specular reflection. This may not be a legitimate inference to be drawn from the table. I should be glad to have this matter made clear. For example, Table XIII, p. 473, gives a column of these ratios for different intensities and at the beginning of work these are 3, 5, 3.5, 4, 2.1, 4.8 for the six different intensities tried. Why should there be such an enormous difference at the beginning of the work at 9 a. m? Compare footnote on p. 461, which speaks of a variation of 1 per cent. or less. What factors are responsible for these wide differences in the initial values granting that the ratios between the initial and terminal values are not so variable? It is the ratios that are most important but the other figures are not without significance.

The new test for fixation is of interest to ophthalmologists but will probably not meet with universal acceptance by them. It appears to be a test for maintaining binocular fusion under forced convergence. What a variable thing this is with different subjects, all ophthalmologists know. With selected and trained observers it might none the less prove a useful test. My present feeling is that the first test is a better test of fixation (monocular of course). Additional data as to the conditions of this new test would be very acceptable. Convergence with this stereoscope at 18 is equal to that convergence as ordinarily tested say in meter angles or by Duane's method or even by measuring simply the distance from the eyes to the nearest point at which an object can be seen single. The data quoted from Dr. Posey are obviously contradictory and therefore probably misprints. The nearer the eye the object is placed the lower the ratio should be, yet Table XXI, page 489, shows the ratio at the beginning of work when the object was at 20 to have been 5.66, though the illumination was less favorable, while the ratio at 22 was 3.7 in one case and 3.6 in the other. On its surface this indicates inconsistency in the test of the same description as the inconsistency in Table XIII mentioned above.

The authors call attention to the significant fact that Chart I shows for position IV "still a considerable loss of efficiency produced by the three systems of lighting." They rightly conclude

that "evenness of surface brightness is not the only factor in a lighting situation which may influence the amount of loss of efficiency sustained by the eye as a result of a period of work." So also Table XXIII shows that the tendency to produce discomfort is still marked if the direct system is used even in position IV (with all the sources behind the observer and no glaring surfaces in front). The time limen is 57 for direct but 101 for indirect, *i. e.,* it takes 75 per cent. longer to produce discomfort with indirect than with direct illumination when the observer is reading. I think they do not call attention to the important fact that when not reading the time limen is not nearly so much longer for indirect than direct, *viz.,* 235 direct, 265 indirect, is only 13 per cent. longer than direct. It pleased me very much to find this feature so well brought out by these tests. As there is no reason to believe the observers were on the watch for it, it cannot be attributed to expectant attention, as it might have been if I had reported it, for it is what I should have expected from my personal experiences and sensations with different ways of lighting, though high authorities in illumination do not agree with me. I believe that even if the sources are all out of sight and the brightness of the surface of the book is the same in both cases the eyes will feel more discomfort and loss of efficiency when the light is not diffuse but comes from a relatively small source and therefore one of high brilliancy. In other words while it is an enormous advance toward comfort to put the direct source behind and so out of sight of the reader it still leaves much to be desired if the source is one of high intrinsic brilliancy and therefore small and relatively concentrated. For many years I have given my patients a rough and ready test to determine whether their lighting was bad. If a pencil is held a few inches from the book the shadow, if the lighting is good, should be blurred and indistinct as from a north window. In proportion as it is sharp and defined, the source is small and of high brilliancy and the illumination is harsh. In the experiment above, in position IV, the shadows cast on the page when reading under the direct system would be markedly different from the shadows cast in the same position under the indirect system. With the observer not reading but looking at the wall in front of him this factor would become subordinate.

Dr. Percy W. Cobb: We have presented to us in this paper[1] descriptions of various lighting installations with detailed photometric data, as well as descriptions of other sets of conditions under which the eye is called upon to work; and alongside of these the results of a test from which conclusions are drawn as to the loss efficiency of the eye resulting from a period of work under each of these several conditions. This seems to me to sum up the tendency of the paper in spite of the disclaimer which appears in the last paragraph to the effect that "the purpose has been primarily to procure methods of working and to find out, as broadly as one may, the applicability of these methods to the problems surrounding the hygiene of the eye."

The quotation suggests to me an important omission on the part of the authors, all the more likely to be overlooked because of the completeness of description in other respects; and I wish here to raise the question: How far may the results of the test as applied be trusted as a true measure of the loss of efficiency of the eye?

It is to be remembered that the test is original with one of the authors and has not, with one exception, been used by any one else. The work done with it has almost entirely been confined to its application, as in the present paper, to the eye before and after a period of work under specified conditions. The mode of procedure has been described but nowhere have we had any full and detailed account as to its susceptibility to influences other than the state of efficiency or of fatigue of the eye. Such information as we have on this latter question is limited to a few general statements which have appeared from time to time in the course of the papers of one of the authors and since the bulk of the work under discussion is taken up with the reporting of the results of the test under the diverse conditions of the experiments, it seems to me that we have the right to ask for much more convincing proof than we have as yet had that the results truly indicate loss of efficiency of the eye.

Photometrists will no doubt agree that in the photometry of lights of identical spectral character (or identical color) one may reproduce his own results to within a fraction of one per cent. The eye can equate to within about that limit of accuracy. If, however, we wish to know what are the fluctuations in the sensi-

tivity of the observer's eye while the measurements are in progress, we see at once that they are included in that fraction of one per cent., and the mean deviation of the results from their mean or the probable error may either of them be taken, for purposes of comparison, as the index of such fluctuations.

Now the method that we are at present considering measures fluctuations of the sensitivity of the eye. In footnote 14, page 461 it is stated that five separate tests of three minutes duration on the same observer taken with twenty minute rest-intervals, and taken under identical conditions, gave results whose variations always fell within the limit of one per cent.[2] It is to be remembered that the analogy to this is not the accuracy with which the photometrist may reproduce his measurement, but the accuracy with which he may reproduce his probable error or his mean variation.

It may be that this analogy is not permissible in the present case. The test method is, as far as I know, different from any procedure heretofore recognized and its limitations may be much less than those of the methods recognized by psychologists and sense-physiologists generally. It is nevertheless a matter of general opinion, I find, among those who have up to the present conducted investigations of this character on the performance of sense-organs, that quantitative results are not to be relied on for reproducibility to within one per cent. when obtained in a few minutes, and they have been driven to much more time-consuming and laborious methods to arrive at results which they consider admissible.

Such methods are of course prohibitive for the purpose of the authors. They might however be applied once for all to settle the points on which the method is open to presumptive criticism. It seems to me that a thorough-going investigation of the method on this plan, not only as to reproducibility but in other respects, is not only possible but much to be desired by those to whom the paper is addressed.

There is another point on which there seems to me to be room for more than one opinion. That is, that in the application of the test as used by the authors of the paper the observer is in full knowledge of all its details. He knows exactly what the test-object is that he is looking at, and that it is identically the same

and at the same distance before and after the work-period. Without any question as to the honesty of the observer in wishing to report exactly as he sees, I think it will be found, and even stated by the observer himself in many cases, that he has the utmost difficulty in keeping his preconceptions separate from his judgments. I mean this remark to apply not specifically to the work under discussion but to such work as I have been concerned with, and in general to quantitative work on the sense-organs. The newness of the method and the importance of the conclusions to be drawn from its results would seem to warrant experimental justification of this feature of the test for the exact situation in which the test is used, especially in view of the fact that the opinion will be found to be fairly general that there should be one or more factors in the experimental procedure, unknown to the observer except as, through the particular sense-channel under investigation, he may get knowledge of them that shall determine the result of the experiment.[3]

In making reference to the possibility of the test being subject to influences other than the state of efficiency or fatigue of the eye, the fact in mind was that in the greater part of the work reported in this paper the tests were conducted with the observer at the same point and under the same lighting conditions as during the work-period. That is to say, in this portion of the work the test was not conducted under the same conditions in any two different experiments whose results are compared. More than this, from the information at hand I cannot see that the intention of the authors to conduct the test under eye-conditions identical with those of the work-period was fulfilled. In footnote 8, page 453,[4] it is stated that during the work-period the book was held at an angle of 45° and it is there also implied that the observer was permitted to assume a comfortable reading position. From what is said further in this note, and from inspection of Figs. 2, 3, and 4 it seems clear that the track carrying the test-card was horizontal. The natural inferences are that the eyes were directed downward at an angle of about 45° during the work-period, that being probably the most comfortable reading position under the circumstances as stated, and that for the test they were raised to a horizontal direction. The book—a large white area in the visual field—is at the same time removed, and

by the shift of the line of vision the light-source and bright areas in the upper part of the room are thrown by the amount of that shift nearer to the center of the visual field. This gives in effect neither uniform conditions for the test in different experiments; nor does it give in any particular experiment like conditions, as far as the eye is concerned, for the reading period on the one hand and for the tests conducted before and after it on the other. Now the test, involving as it does continuous fixation of the small mark on the test-card, does not call for the same performance on the part of the eye as does reading where fixation is momentary and continually shifting; and it is by no means certain that the two processes are equally affected by the conditions. In other words the difference in the results of the test in any two of these experiments may be due, in part at least, to the difference in sensitivity of the test conducted as it is under different conditions.[5] It may be said, at any rate, that a reasonable doubt exists on this point and that nothing has so far been done to establish the fact in question.

What has been said in the foregoing may be summed up in a few words. The fact that there is in the test method as used by the authors no check by which bias on the part of the observers may be ruled out, and the fact that it has not been shown whether or not the test is influenced by the variations in the conditions surrounding its application, throw a reasonable doubt on the question whether its results truly reflect the loss of efficiency of the eye.

Such doubt may be due to misapprehension of the facts or to erroneous premises. I think, however, that the doubt will be found fairly general among those presumably qualified to understand, and might be cleared away by a thorough-going investigation of the test-method, based on experimental procedures which are beyond dispute.

The illuminating engineer can make application of such a test, provided he has unqualified assurance of its validity, and proper instruction. For these he must look to the psychologist or the sense-physiologist. The authors will add immensely to the value of their work by supplying them.

FOOTNOTES.

[1] This discussion applies to the paper of Drs. Ferree and Rand presented at the Convention of 1914 (these TRANSACTIONS, Vol. X, pp. 448-501). As for some reason it could not be published in its proper place it is given here, with such additions in the form of footnotes as have been found necessary in view of the contents of the present paper.

[2] Although the mean variation of the ratio, time clear: time blurred, is mentioned in the footnote cited it is to be remarked that this 1 per cent. variation applies strictly to the time seen clear. The corresponding variation in the ratio will be found to be 4.5 per cent., assuming 140 seconds in 180 as the average time seen clear. It is not plain why the results are stated in terms of the ratio, while the mean variations are given as applying to the time seen clear. This fact throws doubt on the mode of derivation of the mean variations given in Table IX of the present paper.

[3] It is by no means impossible to introduce a variable factor in the test, unknown to the observer. Such a factor would be furnished by the use, in different experiments, of slightly different test-cards. These might be made from cards originally identical by obliterating the space between the i and its dot in varying degrees with a fine pen. For the individual cards of such a set the reading distances should be slightly different. They could be so selected as to be used at the same distance and the difference could reasonably be expected to appear in the results without being evident to the observer during the progress of the test. This would give an answer to the question as to the importance of the factor of expectation in the observer.

[4] See also Note 4 following the present paper. It is difficult to imagine a comfortable reading position with the book held at an angle with the vertical unless the eyes are directed downward from the horizontal to almost the same degree.

[5] This contention is frankly admitted in Note 7 at the end of the present paper: "It was found that the effects of smaller differences in lighting conditions could be detected when both the three minute records and the work were done under the lighting conditions to be tested."

It is argued therefrom that the method is thus more sensitive and not open to objection since the result is a consequence of the tests and the work combined, done under the lighting conditions to be tested. But how in such a case, to illustrate, as is implied in the quotation? If no result is observed when the illumination conditions for the test are standardized, and a positive result when they are conducted under the conditions to be investigated, it would appear that the result is logically to be ascribed to the conditions surrounding the tests. There would be no objection to the inclusion of this effect in the result if there were in practical life any work that the eyes are called upon to do at all comparable with the effort that such a test demands; and if the eye conditions were actually, as well as nominally, identical for the tests and the intervening work-period.

The objection to the standardization of the test-conditions raised by the authors further on, namely that slight differences in the level of adaptation will materially affect the results, applies with equal force to the procedure of the authors as indicated by what I have just said. The necessity emphasized for the control of the "whole field of vision with its complex distribution of light and shade" applies equally well as an objection to the change in the distribution of light on the retina brought about by shifting the eyes from the oblique reading position to the horizontal position demanded by the test. The statement (Note 4) that "Care was taken to have the eyes sustain as nearly as was possible the same general relations to the objects of the room. . . . . ." contains nothing to imply that such a shift was avoided.

Dr. C. E. Ferree (In reply): I agree with Mr. Cravath that our results for the moving pictures selected probably show less fatigue than would be shown in the average by a wide testing of moving picture houses. For example it is stated in the text: "The tests were conducted in a local theater, selected primarily because of the favorable conditions that prevailed. The definition at the screen was good and the pictures were unusually steady and free from flicker. The conditions were, we think, fairly representative of what is found in the better class of motion picture houses." I should like very much for comparative purposes to test the effect produced in some of our lower grade houses, especially on a Saturday night when frequently the rate at which the pictures are given to the eye is very much increased. We hope later to make a more extensive investigation of motion picture effects. This investigation was made primarily to find out whether our test would show an effect of motion pictures on the eye.

Dr. Black says: "The authors state 'It is a question whether any practical good can accrue to the practise of lighting from a knowledge of just what part of the visual apparatus it is that falls off in function as the result of an unfavorable condition of lighting.' It would seem that this is of prime importance." I should have appreciated it very much if Dr. Black had elaborated on this statement. I should be glad to know the opinion of the opthalmologists with regard to the importance of pursuing the analytical study.

I am very glad indeed for many reasons to take into account anything that Dr. Lancaster may have to say about the work we are doing. I shall mention only one of these reasons here. Realizing from his intimate knowledge of eye testing something of the difficulties one may expect to find in applying an unfamiliar test, he made a trip to our laboratory before attempting any work at all with the test, to find out just how we made the application ourselves.

Dr. Lancaster says in the first paragraph of his discussion: " . . . their methods seem to give consistent and reproducible results in their hands." Apropos of this statement by Dr. Lancaster a word of comment and explanation may not be

out of place here.[1] So far as the test has been applied by us, the mean variation from test to test has been very much less than any experimental variation, from which we have drawn differential conclusions with regard to the relative merits of lighting conditions, and no results have been or will be published as significant in a variation of lighting conditions in which the change in result produced is not safely in excess of the mean variation of the test. In fact, because of the amount of this excess of the experimental variation over the mean variation, we have not as yet felt urged to compile and publish full data on the reproducibility of the test.

Dr. Lancaster says in the second paragraph of his discussion: "I am glad to see that they (the authors) have apparently abandoned their view that the first of the three tests is a test of the efficiency of the accommodation and now speak of it as 'a test of the ability of the eye to hold its efficiency for a period of work' and as 'a test for loss of efficiency for clear seeing'; that is they do not commit themselves to any theory of how the test works." I am somewhat puzzled to understand how Dr. Lancaster has gotten the impression from anything we have published that we considered the test referred to be of itself anything but a test of the aggregate loss of functioning of the eye. The test was not designed to be analytical in nature, but merely to show changes in the eye's ability to see clearly for the three-minute interval consumed by the test before and after work. This is shown by the title of the first paper "Tests for the Efficiency of the Eye, etc.," and in the discussions of the test in the same paper pp. 45-50 in which it it always referred to as a test for the efficiency of the eye not as a test for the efficiency of the accommodation or any other single function. Indeed on p. 50 of that paper the statement is made very explicitly. "This ratio as stated earlier in the paper expresses the efficiency of the eye for clear seeing for an interval of three minutes at the time at which the test was taken." In connection with the test for aggregate effect, however, tests designed to be analytical in nature were made, namely, tests for changes (a) in the response of the retina to colored and colorless light; (b) in the rate of exhaustion; and (c) for the rate of recovery of the retina; and (d) for the rate of lag of sensation;

[6] See also discussion of Mr. Cravath's paper, TRANS. I. E. S., 1914, vol. IX.

also tests for loss of efficiency of the fixation muscles. It was only because these tests showed very little if any significant effect that we suggested very tentatively, subject to the results of a further test bearing more directly upon the accommodation muscles, that the results gotten in the general test were due largely to loss in efficiency of the accommodation muscles. The first test was not designed to test for losses in power to accommodate alone, nor was it used for that purpose. So far as its relation to the eye is concerned, it was used merely as an explorative test to separate out good from bad hygienic conditions rated according to an aggregate effect on clear seeing.

Dr. Lancaster further says: "I am convinced that the accommodation has nothing to do with the blurring but that it is a retinal affair and depends chiefly on steadiness of fixation—immobility of the eye, and that in turn on attention to a by-no-means-negligible degree." It may perhaps be inferred from this statement that, since the greater amount of blurring takes place under the conditions which would distract the fixation most and therefore lead to the greatest unsteadiness of fixation, Dr. Lancaster considers that the blurring comes as an effect of unsteady fixation on the functioning of the retina. This point of view carries the writer back to a group of problems in the study of which he spent four years.[7] Space cannot be taken here to go into that work. It is sufficient to say that since the time of Fechner,[8] it has been held that involuntary eye-movements, or unsteadiness of fixation, are of prime importance in keeping the retina from becoming exhausted during the course of a working day. That is, so far as the functioning of the retina alone is concerned, unsteadinesss of fixation or movements of the eye both voluntary and involuntary work for clear seeing, not blurring; and the lighting system which by the strain it puts on the muscles causes the greatest unsteadiness of fixation, should be the system which causes the least and not the greatest blurring in the test following

[7] See C. E. Ferree, An Experimental Examination of the Phenomena Usually Attributed to Fluctuation of Attention, Amer. Jour. of Psych., 1906, XVII, pp. 79-121; The Intermittence of Minimal Visual Sensation, *ibid*, 1908, XIX, pp. 57-130; The Streaming Phenomnon, *ibid*, 1908, XIX, pp. 483-504; The Fluctuation of Liminal Visual Stimuli of Point Area, *ibid*, 1913, XXIV, pp. 377-410.

[8] See Fechner, Pogg. Ann., 1838, XLIV, p. 525; Helmholtz, Physiol. Optik., 1896, p. 510; Fick and Gürber, Archiv für Opthal., 1890, XXXVI, (2), p. 246; Hess, *ibid*, 1894, XL, (1), p. 274; MacDougall, Mind, 1902, XL, p. 316; 1903, XII, p. 289; and the present writer, *loc. cit.*

the period of work. And so it would, as is abundantly shown in the references cited on the effect of eye-movement on the functioning of the retina, if the unsteadiness of fixation and accommodation caused by such a lighting system did not also interfere with the clear imaging of light on the retina that is needed for clear seeing.[9]

In paragraph five Dr. Lancaster expresses the belief that while the major significance should be attached to the change of ratio of time seen clear to time seen blurred before and after work, considerable significance should be attached also to the difference in the value of this ratio before work for the different lighting conditions. One of the reasons he gives for this is that in Table XIII, which shows the results for six tests on the effect of variation of the intensity of light with the indirect system, and of variation of intrinsic brightness of the ceiling spots above the reflector produced by using socket extenders with some of the shorter lamps, these initial ratios seem to vary as much if not more than the final ratios, or as the change in ratio before and after work. These initial ratios were respectively 3, 5, 3.5, 4, 2.1, 4.8. If, however, Dr. Lancaster will observe the table closely, he will see that the ratio of the working distance to the acuity distance is not the same in all of these cases. The same ratio of time clear to time blurred should, therefore, not be expected even were the lighting conditions the same. Whenever, for example, the working distance has been chosen closer to the eye, proportionate to the acuity distance, a higher ratio of time clear to time blurred should be expected. This, it will be seen, happened in all but one of the above cases in spite of differences in lighting conditions. However, everything else being equal, it is perhaps true that the more unfavorable lighting condition will cause greater proportionate blurring in the initial record observation,[10] and if so, the results of this initial observation may have some diagnostic value. We have, however, never felt it safe to use the results of

[9] That is, unsteadiness of accommodation interferes with the clear imaging of the light on each retina, and unsteadiness of fixation with the imaging on functionally corresponding areas of the two retinae. Functionally corresponding is used here in the usual sense, namely, areas of the two retina which in binocular seeing combine their images into one. If the images do not fall fairly accurately on these areas, doubling and consequent blurring result.

[10] The above statement is made with reservation. The point will be discussed more fully later.

the initial observation in this way because they are, when compared from day to day as they would have to be in this case, the least reproducible feature of our test. In the way in which we are accustomed to evaluate our results, the deviation from close reproducibility of this feature of the test enters into the evaluation of the favorableness of lighting conditions for the eye no more than is represented by its comparatively slight effect on the sensitivity of the test. That is, we so conduct our test and evaluate its results as to give negligible weight to this item, the successful accomplishment of which is shown in the small mean variation gotten in the actual work of testing. Dr. Lancaster thinks the variation of the ratios for the initial test quoted above has all the more significance when compared with the estimation of the degree of reproducibility of the 3-minute record given in footnote 14, p. 461. Here it is stated that with the practised observers we used the maximum variation of time clear in five consecutive records for the fresh eye with a rest interval of 20 minutes between each record has always fallen within 1 per cent. for all the observers whose results have been published. The following points will show that little stress should be laid on this comparison. (1) The reproducibility tests (for which the 1 per cent. reproducibility was quoted) on the fresh eye were made with exactly the same ratio of working distance to acuity distance. In the tests of which Dr. Lancaster quotes results this ratio was different. (2) The reproducibility tests were also made always on the same morning with a 20-minute rest interval under very favorable and always identical rest conditions. The tests referred to by Dr. Lancaster were taken on different days. And (3) the 1 per cent. deviation in the reproducibility tests were from the average of the time seen clear; the deviations quoted by Dr. Lancaster were in the ratio time clear to time blurred.

In the sixth paragraph Dr. Lancaster says: "The new test for fixation is of interest to ophthalmologists but will probably not meet with universal acceptance by them. It appears to be a test for maintaining binocular fusion under forced convergence. What a variable thing this is with different subjects all ophthalmologists know. With selected and trained observers it might

none the less prove a useful test." We do not quite see how its variability from observer to observer affects the purpose for which we have used the test. Our purpose is to select practised observers and see how much the power of each to maintain binocular combination of images is affected by both the work and the test under a given lighting condition. The point of comparison is not at all one of individual differences, but how much for a given individual the power to maintain the binocular combination is affected by work under the lighting conditions which are being tested. I do not think, therefore, that Dr. Lancaster's point is relevant to the purpose for which the test has been used, nor can I see that it constitutes any objection to the use of the test to supplement the tests now used by the ophthalmologist for the fixation muscles. I have already pointed out in the text that it may be more important, even in the work of the clinic, to determine the eye's power to sustain co-ordinated muscular action than it is to determine the maximum pulling power of the individual muscles by a momentary effort, for it is obviously the power to sustain co-ordinated muscular action that is of prime importance in determining whether the eye, so far as the fixation muscles are concerned, is able to carry on sustained work. In fact sustained co-ordination is just what is demanded of the eye in continuous work. It seemed to me, therefore, that this type of test more nearly measures what is demanded of the working eye than do, for example, the ordinary abduction and adduction tests.

Later in this paragraph, Dr. Lancaster's discussion shows that he has misunderstood our data. He has apparently understood the table reading "Distance at which test object is normally seen single" to mean that nearest point at which it can be seen single by a maximum effort of convergence. This is given in the table as 18 cm. for the observer used. This distance was not the nearest point at which the test objects could be seen single with maximum effort, but the distance at which, as the wording of the heading indicates, they were most easily held combined. Therefore, when the test objects are set either nearer to the eyes or further away, they will be held combined with effort. The observer whose results are given in Table XXI, in order

to put the eyes under strain to combine these images, preferred to set the objects at a greater rather than a less distance than 18 cm. from the eye. The 22 cm. distance, therefore, should and did give for the fresh eye a smaller ratio of total time single to total time double for this observer than the 20 cm. We should have made it clear in discussing the test that a point either nearer or further than the most favorable could be used and that the latter was used in case of the observer whose results were given in Table XXI. My explanation of the oversight is that I had always used the other condition myself and had become accustomed to think of the test in that way. In explaining this point we have doubtless also explained the contradiction which Dr. Lancaster thought to exist between Dr. Posey's clinic data and the results of Table XXI. We are deeply indebted to Dr. Lancaster for calling our attention to the point. Either an explanatory footnote should have been appended to the table or the results of another observer should have been selected.

Dr. C. E. Ferree (In reply to Dr. Cobb): In replying to Dr. Cobb's discussion I am somewhat in doubt whether to consider it merely a discussion of the paper immediately preceding the present one or as being intended to apply also to the present paper. Since it has been revised by appending footnotes which take into account the contents of the present paper, the natural presumption is that in as far as the body of the paper is not modified by these footnotes, what is said is meant to apply to the present as well as the preceding paper.

In a brief review of the beginning of the discussion I may be pardoned perhaps for calling attention to the fact that in the quotation made from our paper in his opening paragraph he has abstracted from its context just what was favorable for the point he wished to make and ignored the rest. The quotation should continue: "While in many places attention has been called to results that have seemed to have general significance, the intention has been, in general, to limit all comments and conclusions strictly to the conditions under which the work was done." This in connection with the quotation made seemed to me at the time to be a fair statement of the case and it seems to

be so to me yet. The conditions under which the work has been done have been made clear at every point and not the slightest attempt has been made to draw conclusions beyond these conditions. Moreover, to do this is not in the least degree contradictory to the purpose expressed in the sentence quoted, namely, "primarily to find out, as broadly as one may, the applicability of our test method to the problems surrounding the hygiene of the eye." It was well known, for example, that the work was being done by methods the precision and applicability of which were under investigation for each new set of conditions employed. This investigation, however, I need scarcely to state, was not a part of the actual work of testing. It was completed and the observer trained to a satisfactory degree of precision before that work was begun. That is, not until an observer selected on the basis of both his freedom from optical defects and a precision already shown in other work in physiological optics, had also attained to a satisfactory degree of precision in the 3-minute record under a given lighting condition and in the 3-hour test under several conditions, and a careful comparison of results in the actual work of testing had shown that the variations produced by changing the conditions to be tested was by a large margin safely in excess of the mean variation from the average for each of the conditions tested, were his results accepted as significant. Then and not until then were data incorporated into tables and curves purporting to represent the effect of the conditions tested upon the ability of the eye to sustain clear seeing. It is clear then, I think, that both of these procedures, the preliminary investigation of the precision and applicability of the test to each new set of conditions and the actual work of testing these conditions have been features of our work just as was stated in the concluding paragraph referred to, and not the latter alone or predominantly, as was gratuitously inferred by Dr. Cobb. Furthermore, until a wider range of work is covered we intend that our purpose shall remain primarily that of finding out as broadly as we may the applicability of our method to new conditions; but that purpose, it is obvious, when satisfied should not and will not in the least prevent us from doing the actual testing for these conditions; and the result for this testing, it is scarcely needful to say, may reasonably be expected to make up

the larger part of future papers as they have of the papers already presented, without the liability of anyone's misunderstanding either what has been intended or what has been done.

In his third paragraph Dr. Cobb charges that we have not published enough data in our papers to insure the reader of the reliability of the methods employed, and leaves it rather pointedly to be inferred both here and elsewhere in the discussion that to the best of his belief sufficient precautions have not been taken to guard the results against the influence of extraneous factors. We regret that this charge is not more specific, for then it not only would have more meaning but it could be answered in briefer space. However, let us recall (1) just what precautions have been taken that the influence of variable factors extraneous to the effect of the conditions tested should not enter into the conditions of the experiment to an extent that would be harmful for the purpose for which the experiment was used, and that no variations produced by such factors should be confused with the variations produced by changing the conditions to be tested; and (2) just how much data has been published with regard to these precautions up to the present time. Before beginning and preliminary to the work the results of which have been published in our last three papers, a study was made for the express purpose of finding out just what factors would be likely to influence the results of the work, and methods were devised for controlling these factors. Obviously a study of the influence of a factor can be made by varying that factor when all other conditions are held constant and noting the effect on the results. Such a study could have gone on endlessly and the presentation of its results would have consumed endless space. Moreover, such work leads to nothing once the factors are known and methods have been devised to control them. That type of investigation of the test was pursued to some extent, however, by Mr. Cravath, and the results of his work were published. In our own work instead of trying to find out at needless length what effects could be produced by means of a procedure that never would be permitted in making a test, every care has been taken to control the factors the possibility of the influence of which had been revealed in the preliminary experiments; and the effectiveness of the control

was checked up by carefully determining the mean variation of the results for each set of lighting conditions. The size of this mean variation is, it is well known, the measure of the net influence of the factors extraneous to the conditions which are being tested. When, for example, two lighting systems are being tested and it is found that the difference in the average result obtained for the two systems is not greater than the sum of the mean variations for both, the conclusion can not be certainly drawn that a significant difference in effect is produced by the two systems. This method of treating results has been devised as a gauge on the influence of variable extraneous factors and should be too well known to need further discussion here. Let it be sufficient to state that this check upon the absolute and relative value of the influence of such factors has been carefully applied at every step in the work. This we have already stated. We have also given a statement of the care that was exercised in the selection of observers based both upon their optical condition and the precision they had already shown in other work in physiological optics; and a very detailed description of the careful method that was used in training the observer separately on each feature of the test with careful attention to the size of the mean variation throughout. Short of a paper devoted to the test, the data that has been published on the above points can scarcely be considered insufficient. Statements of the precautions that have been taken in the control of the extraneous factors and in the selection and training of observers have been published as the need arose in all four papers and amplified both in the public and written discussions both of our own papers and Mr. Cravath's. A statement of the standard of precision to which each observer must attain in the 3-minute records before he was allowed even to participate in the practise series of the 3-hour tests was made in connection with the publication of the second and third papers[11] and again in the fourth paper. A comparison of the mean variation for each lighting condition with the variation produced by changing the condition to be tested was given as a regular feature of the presentation of the results for the work of the fourth paper. Here we are

[11] The second and third papers, it will be remembered, were published simultaneously.

working with smaller variations in lighting effects and there was need to show the comparison. In the presentation of the data of the second and third papers, however, the comparison was not considered necessary. The changes made in the conditions tested in that work were so large and the variations produced by changing the conditions tested so absurdly much greater than the normal variation for each of the conditions tested that the comparison seemed, as I have already said, not only needless but distinctly ostentatious. A representative numerical statement of the comparison, however, is given in the fourth paper. Moreover, a detailed statement will be given in a final paper devoted to the test. We have taken considerable care to describe the exact conditions under which the work was done, or to give precautions that were taken to guard against the influence of variable factors.

In the fourth and fifth paragraphs Dr. Cobb compares our work with photometry in a way that needs not only elucidation but some correction. There is, for example, absolutely no difference between the two kinds of work that would make one capable and the other incapable of precise performance. In photometry a judgment of brightness equality is employed which may range or vary through a difference threshold on either side of equality. In our work a visual acuity judgment is employed which is nothing more nor less than the judgment of a space threshold. Of the two the latter is the more precise even when the judgment of equality is made between two lights of the same composition. A different use is also made of the judgment. In photometry the judgment is used to equate the power of two lights to arouse equal sensations with the eye at a given standard of performance. In our work the judgment is used to measure the ability of the eye to hold itself up to a given standard of performance from beginning to end of a period of work under this or that lighting condition. In careful work when the photometric judgment is used to equate the power of two lights to arouse sensations of equal intensity the observer is first trained to a satisfactory degree of precision in making the judgment before the work of photometering is done, and this photometering itself is checked by the degree of reproducibility of the results obtained, or the size of the mean variation. If, however, the photometric judg-

ment were used to measure the power of the eye to hold itself up to a certain standard of performance from the beginning to the end of a period of work under a given lighting condition, and we have used it in that way in our work on determining the ability of the retina to maintain its power to discriminate brightness differences through a period of work under different lighting conditions, the method of training the observer and the check on the precision of the work should be carried out just as we have carried it out in our work on the power of the eye to hold itself up to a certain standard of acuity. That is, precision is first attained in making the photometric judgment. The observer is then given a period of training and practise in which the precision is compared before and after work under a given lighting condition. As a third step the observer is allowed a period of practise under different lighting conditions until a satisfactory degree of reproducibility is attained in the figure or ratio expressing a comparison either of the sensitivity or the size of the difference threshold before and after work. And lastly in the actual work of testing, the final results are compiled from a large number of determinations, and the precision is checked up by the size of the mean variation. It is, for example, very misleading for Dr. Cobb to state in reference to our work as he has in the sixth paragraph:

> It is nevertheless a matter of general opinion, I find, among those who have up to this present time conducted investigations of this character on the performance of the sense organs, that quantitative results are not to be relied on for reproducibility to within 1 per cent., when obtained in a few minutes, and they have been driven to much more time consuming, laborious methods to arrive at results which they consider admissible.

Dr. Cobb points out that the test is original with the authors and should, because it is so very new, be subjected to probation and searching criticism before it be given a place in the sun along with methods hoary and worn with service. Since the question is raised it might be well to find out just how new in its essential principles the method really is. Just two features are involved in the test method,—one is that visual acuity or clearness of seeing may be measured by the smallest visual angle the eye is able to discriminate; the other, a principle equally old, is that a loss of efficiency or depression of function in a machine,

apparatus, or living organ or organism will show out more plainly when a prolonged rather than a momentary performance is required. Our intention has been to combine these principles in their simplest terms into a test of the comparative power of the eye to sustain its power of clear seeing or aggregate functional activity under different conditions of lighting and with different kinds and conditions of use. Allow me to quote from a statement of the principle of the test.

The principle of the test will be remembered from the earlier papers. It is merely the conventional acuity test subjected to certain features of standardization for the sake of greater reproducibility and made into an endurance test to give it additional sensitivity. The older test had not been found to be sufficiently sensitive to fatigue conditions to warrant adoption in our work. This test is not in fact meant to be a fatigue test. It was designed to test the dioptric condition of the eye and may be used with more or less success perhaps as Dr. Cobb used it "as a test of how far a given lighting condition is conducive to clear seeing with a maximum of momentary effort" (provided, however, it is used with a degree of precision and in connection with a plan of experimentation that will warrant the drawing of conclusions); "but it has not the essentials of a fatigue test nor of its converse, the ease with which clearness of seeing is attained, which is what is needed primarily for the selection of lighting conditions for the greater part of the work that we are ordinarily called upon to do. Almost if not quite as good results may be gotten with it, for example, after work as before, when there is every other reason to believe the eye has suffered considerable depression in functional power. The reason for this is obvious. Although greatly fatigued the eye can, under the spur of the test, be whipped up to give almost if not quite as good results as the non-fatigued organ when only a momentary effort is required. If fatigued, however, it cannot be expected to sustain this extra effort for a period of time. The demonstration of this fact had led early in our work to the introduction of the time element into the test. The principle involved is not a new one. It is merely the application of a very old and well known one to the work of testing for optical fatigue. If, for example, a sensitive test is wanted for the detection of fatigue in a muscle, as good results cannot be expected if the test requires only momentary effort on the part of the muscle as would be attained if the endurance of the muscle were taken into account. For our purpose, therefore, the old acuity test has been made into an endurance test, in which the fatigue or loss of functional efficiency of the eye is measured by its power to sustain clear seeing for a period of time. As such it should and does show a sensitivity for detecting fatigue far beyond what can be attained by the older and more established test when it is used for that purpose."

The discussion in the eighth paragraph of the influence of expectation or pre-knowledge on the part of the observer is also absurdly misleading. The discussion is introduced by the sentence "That is, in the application of the test as used by the authors of the paper the observer is in full knowledge of all its details." Obviously the reader is meant to infer from this statement that the observer is put under some exaggerated or special condition of pre-knowledge not proper to a well conducted experiment. Later when pinned down to cases it develops that the critic is able to name only two items of which the observer has knowledge, namely, the test object and the fact that in the 3-minute records it is always kept at the same distance after work as before. Why it is necessary in order to have a properly standardized acuity experiment to give the observer a knowledge of the test object and to change the type of judgment from recognition to that of a space threshold, the surest and most reproducible of the sense judgments, has been discussed at length in our first and fourth papers. The second point, it is obvious, can not be of the slightest consequence. As a matter of fact the observer does not know unless he is told that the distance of the test object is the same after work as before. The experimenter knows this, but there is absolutely nothing in the conduct of the experiment to tell the observer that the distance of the test object has not been changed in the 3 hours that have elapsed since the first record has been taken. But even if he did know it had not been changed, the knowledge could not have the slightest influence on his judgment of when the space between the dot and the vertical line in the letter i sinks below the threshold of discrimination, how often it goes below the threshold, or how long it stays there; for it drops below the threshold not because of any change in the distance or size of the test object or its parts, but because the eye is not able to hold its adjustment for clear seeing. For a somewhat full discussion of the importance of the factor pre-knowledge in experiments in physiological optics, of how it may be eliminated and compensated for in accord with the best principles of experimentation at the present time, the reader is referred to Note 1, of the paper "Some Experiments on the Eye with Inverted Reflectors, etc.," which appears on previous pages of this number of the TRANSACTIONS.

Up to this time in Dr. Cobb's discussion I had understood that his doubts as to whether the results of our test have really measured the loss of efficiency, rested on several contentions: the fact that only one other investigator had published results on the tests besides ourselves; his claim that no data has been published that could be considered as showing a safeguarding of the results against the influence of extraneous factors; the charge that the observer knows what the test object is and that it is the same distance from the eye in the records taken before and after work; the recrimination that such precision as was attained by our observers in the course of several months of training in one feature of the experiment could not in the opinion of the experts of his acquaintance be obtained in a few minutes; etc., etc. In the ninth paragraph, however, it develops that:

> In making reference to the possibility of the test being subject to influences other than the state of efficiency or fatigue of the eye, the fact in mind was that in the greater part of the work reported, the tests were conducted with the observer at the same point and under the same lighting conditions as during the work period. That is to say, that in this portion of the work the test was not conducted under the same conditions in any two different experiments whose results are compared.

Dr. Cobb's contention here is that the 3-minute record before and after the reading period should have been taken in a separate test room having always the same intensity and distribution of light regardless of what distribution and intensity of light the eye was exposed to during the 3 hours of reading which intervened. That is, immediately at the close of this period the observer would have been brought into a room for the 3-minute record in which for a part of the work the distribution effects would have had to be widely different from the previous 3-hours exposure (the distribution series), and for another part of the work both the distribution and intensity would have been widely different (the intensity series). Thus the eye in every test would have taken the record at the close of work in a different state of adaptation or sensitivity than at the beginning. How very futile and inadvisable this would have been more especially for the work in the intensity series I scarcely need once more to point out. Even in the work in the distribution series, the only part of the work for which Dr. Cobb's proposal

could have at all been considered, very great care would have had to be exercised to see that the separate room was always illuminated with exactly the same intensity of light that was used in the room in which the reading was done. If the illumination of the two rooms were not accurately the same, a period of adaptation would have had to be allowed before the 3-minute record could have been made, which in case of the record taken after work, would have given the eye opportunity to recover from the fatigue induced by the work. It is obvious that a great deal of difficulty would be encountered in accurately maintaining this control; and if it were not so maintained an error of considerable consequence would be introduced into the work. Moreover, in getting this control, not only the illumination of the test card must be taken into account, but the brightness of the whole field of vision with its complex distribution of light and shade, for this conditions the state of adaptation of the paracentral and peripheral portions of the retina, which in turn exerts an influence on the part of the retina that receives the image of the test object. It is obvious further that this duplication of light and shade could not be made in a separate test room without copying the work room and the lighting system employed in each case, which would of course no longer make of it a separate room. Furthermore, it was found early in the work that the effects of smaller differences in lighting could be detected when both the 3-minute records and the work were done under the lighting conditions to be tested. That is, the total test procedure, which includes both the 3-minute records and the reading, is more sensitive when it is all done under the conditions to be tested, than when a part of it is done under these conditions and a part of it in a separate room. Since the method is more sensitive when the whole procedure is conducted under the lighting conditions to be tested, we can see no reason why even the purist should demand that a part of it should be done under the conditions to be tested and a part of it elsewhere so long as the results are recognized to be the consequence of the 3-minute records and of the reading. There are, it is obvious, two reasons why the method should be more sensitive when the 3-minute records are taken in the work room. (1) The method is more amenable to control when the eye is subjected to no change in lighting

effects in the 3 hours intervening between the two records that have to be compared. And (2) the 3-minute record itself is a task for the eye as well as the reading. The difference between the fatigue it induces in case of the first and second records may be greater under a bad lighting system than under a good. If so, this adds on to the effect of the reading to make up the total effect determined by comparing the two records. Whether it does or not, however, seems to me of little consequence for it is differential of conditions just as well as the reading. That is, if the effect does add on to the effect of reading, the total result is only as if a longer reading period were used. Here, however, Dr. Cobb files his final demurrer (footnote 5): "There would be no objection to the inclusion of this effect in the result if there were in practical life any work that the eyes are called upon to do at all comparable with the effect that such a test demands." Our reply to this would be (1) that there are no tests for acuity, momentary or sustained, comparable in effect with the ordinary use of the eyes for the same length of time. If there were they would not be tests; (2) the effect added is not the total of the strain of the 3-minute record, merely the difference in effect of two, one taken before and one after work; and (3) if an effect is added, the net result is only the same as would be attained if a longer reading period were used.

Dr. Cobb goes on to say that "More than this from the information at hand I can not see that the intention of the authors to conduct the test under conditions identical with those of the work period was fulfilled." He bears this out with a description of the observer's position during the 3-minute records and the reading period, as he interprets it. In the treatment of this point Dr. Cobb's discussion indicates his viewpoint. Apparently it was supposed that the observer sat primly erect with eyes modestly lowered ("at an angle of about 45°") away from the garish effects of the selected products of modern lighting, taking great care to face these products to which it was the sole purpose of the experiment to expose the eyes only so long as was necessary to view the test object for the 3-minute records. Such, he contends, is the natural inference from an inspection of Figs. 2, 3 and 4 (which show nothing but the test object, the track on which it was carried and the observer's empty chair), and

"from what is said further in this note" describing the observer's position, the details of which he fails to give or to reconcile in the slightest regard with his interpretation. I may be pardoned perhaps for pointing out that Dr. Cobb's inference is the natural one on only two assumptions: (a) that he has not carefully read the description of conditions given in the note in question; and (b) that he has taken for granted that the authors have not a sufficient comprehension of what they are trying to accomplish in these tests and of the chief point of significance of the somewhat extensive results they have obtained. Allow me to quote from the description given in the present paper.

Care was taken to have the eyes sustain as nearly as was possible the same general relations to the objects of the room as were sustained when the 3-minute records were taken. This could be done either by holding the head erect, etc., or by tilting slightly backward in the swivel chair used by the observer and allowing the head to relax a compensating amount. So far as the direct optical effects are concerned it would seem to be immaterial which of these positions is chosen, so long as approximately the same field of vision is obtained. The latter is usually preferred by the observer as causing less general fatigue. When taking this position, the book is elevated and held at approximately an angle of 45° (a little nearer to the vertical than this perhaps).

Moreover, the description given in the third paper, while not quite so full as this, differed from it in no way that could lead to Dr. Cobb's interpretation, either as a necessary or a probable criticism. But Dr. Cobb protests finally (footnote 4): "This position can not be comfortable." It is not so comfortable *for the eyes* as the one we were naturally inferred by him to take, but otherwise it is very comfortable indeed. For further proof we can only recommend that he try it. The above description of the reading position of the observer should also render pointless the contention made in the latter part of footnote 5. This contention is:

The objection to the standardization of the test conditions raised by the authors further on, namely, that slight differences in the level of adaptation will materially affect the results, applies with equal force to the procedure of the authors as indicated by what I have just said. The necessity emphasized for the control of the whole field of vision with its complex distribution of light and shade applies equally well as an objection to the change in the distribution of light on the retina brought about by shifting the eyes from the oblique reading position to the horizontal

position demanded by the test. The statement (note 4) that "Care was taken to have the eyes sustain as nearly as possible the same general relations to the objects of the room . . ." contains nothing to imply that such a shift was avoided.

As we have already clearly shown by quoting from the original description of conditions, the reading position was not oblique, hence no shift from such a position to the horizontal is demanded in passing from reading to the 3-minute record. Moreover, that there shall be no abrupt transition from reading page to test card a fixed interval of pre-exposure to a surface of the same brightness and size of the test card is allowed before the 3-minute record is begun.

The footnotes appended to Dr. Cobb's discussion are, I understand, meant to apply specifically to our present paper. All of them have already been covered in connection with the above rejoinder but 2 and 3. Footnote 2 is based on a confusion arising from Dr. Cobb not reading correctly our statement of the standard of precision that must be attained in the practise on the 3-minute records before the observer was allowed to enter on the next stage of the preliminary work. The 1 per cent. is not a mean or average variation. It is an outside limit beyond which no individual variation ever went for the observers whose results were published in the paper. It is somewhat difficult to understand how he could have misread the original statement. This statement is: "For a single series of five tests these variations in the time seen clear in the 3-minute periods have always fallen within 1 per cent. for all of the observers we have used and for all systems of lighting" (TRANS. Aug. 30, 1915, p. 461). A typical mean variation in the time seen clear in one of these practise series of five tests is for Observer R approximately 0.37 per cent.; for Observer G it was slightly smaller. Corresponding to the mean variation in the time seen clear of 0.37 per cent. for Observer R, the mean variation of the ratio time clear to time blurred is 1.4 per cent. We hope this additional explanation will clear up the doubt in Dr. Cobb's mind with regard to how the mean variation was obtained for Table IX of the present paper. In Table IX the mean variation was of the drop in ratio time clear to time blurred produced by making a change in the condition to be tested. This mean variation was taken of the drop

so that the average value of the drop could be compared with its average variation to see whether the change produced by changing the system could be considered as significant. The citation given by Dr. Cobb should not have caused confusion because it was not only clear but obvious from the text just what was done in both cases.

In the brief first statement made of our standard of precision in the practise work on the 3-minute record, it was, we may say, considered more significant for the purpose for which the 3-minute record was to be used in the actual work of testing to show that all of the individual variations fell within a given small limit than to indicate what the average variations were, leaving the reader in doubt as to how wide a range of throw the individual variations might have. As to whether the result was expressed in terms of the time seen clear or the ratio time clear to time blurred seems to me quite immaterial. Both expressions are significant, and one is readily derivable from the other when the time seen clear and the total time of observation are known.

In footnote 3 Dr. Cobb raises again the question already much discussed of the possibility of introducing an objective check on the influence of subjective factors. We have patiently explained several times before that there are two ways of checking up the influence of subjective factors,—the objective check and a careful determination of the mean variation, and that neither one of these possibilities has been overlooked in our work. We tried for several months to devise a means of changing the test object in such a way that an objective check could be had on the registration of the observer without sacrificing the principle of the test. Such a change of sufficient magnitude to be of any definite service could not, we found, be made in the test object which did not at the same time permit the eye to relax its strain at the instant of change, which, it is obvious, destroys the very feature which gives the test its superior sensitivity. The attempt to get an objective check was made, I may say, to offset possible criticism rather than because of any belief that it was necessary for the purpose for which the test has so far been used; for, as we have already stated, a determination of both the maximum and mean variations for the 3-minute records, each one of which

consists of a number of separate judgments, had shown us that the influence of expectation and other subjective factors has been, under the conditions for which the work has been done, of negligible consequence. Dr. Cobb suggests as an objective check that different cards be used in some of which the space between the dot and the vertical line of the letter i be obliterated in different amounts by a fine pen. [1] We have found the change he suggests not to be of any additional service for the following reasons: (1) A change that would be large enough to affect appreciably the amount of time that the angle of separation between dot and line is below the threshold of discrimination is too large to escape the observation of the observer. When the eye goes out of adjustment, the lapse is apparently too abrupt and too great to permit of a change that would not be detectable to the observer with a well adjusted eye to influence significantly the course of the record. That is, a diminution by so small an amount would not put it below the threshold when the eye was well adjusted, nor would an increase by the same amount put it above the threshold in one of the lapses of adjustment. The additional strain, moreover, does not seem to be significantly great. It might be perhaps if the angle of separation which it is necessary to employ were at or very near the threshold of discrimination, but it is not at or very near the threshold of discrimination, as we have explained many times. (2) The check proposed is not directly objective, it could serve only indirectly as a check and very indirectly at that. A test object like the letter E, for example, which could be turned in different directions and the observer be required to tell which way it points is used in acuity tests as an objective check. Here the judgment of the observer is checked up directly by the knowledge of the experimenter. Dr. Cobb, however, proposes to vary the results of the observer by varying one of the factors which is supposed to influence these results, and from the working of this variation to detect whether the observer is judging his experiences honestly. This in experimental procedure is known as the method of concomitant variations, and by common acceptance must itself be very carefully checked up before its results are considered of any significance. The only way it could be checked up would be carefully to determine the mean variation for each change and

compare this variation with the variation produced by changing the angle of separation. This would have to be done before it could be told whether the change was operative and thus even the slightest check be had on the verity of the observer's judgments. That is, in this roundabout procedure one would have to rely fundamentally at every step on the check we have used from the beginning, namely, a careful determination of the mean variation, and the procedure itself invites cumulation of error and uncertainty. Dr. Cobb's proposal is, in methodological procedure, not unlike setting a thief to catch a thief, and is to say the least distinctly meretricious.

SMALL INCANDESCENT LAMPS AND SPECIAL ILLUMINATION PROBLEMS.*

BY ROBERT P. BURROWS.

Synopsis: The paper presents certain improvements in miniature lamps resulting in their increased use in commercial, professional, and industrial fields; a brief study of dry cells and their relation to small incandescent lamps in the various fields together with a suggested method of testing dry cells in order to obtain such data as will enable the proper application of small lamps; and a few interesting examples of how the application of engineering knowledge to comparatively simple devices will increase their usefulness. A few of the many uses of small lamps are also mentioned.

The purpose of this paper is to call attention to the fact that the small incandescent lamps commonly classed as miniature lamps are coming to be recognized as contributing a great deal to certain special fields of lighting. Not long ago small lamps were looked upon as playthings and had little or no commercial application. This was due, partly, to the limitations of the carbon filament in applications where the cost of supplying energy is necessarily high. With the introduction of tungsten as a filament material, a considerably higher efficiency for these lamps was possible. However, it was not until the introduction of the drawn-wire, tungsten filament that the lamps became recognized as having many commercial possibilities. This filament improvement, with its increased efficiency and strength, did more than anything else to place miniature lamps in the position they now hold. High efficiency made possible the use of dry cells as a source of energy.

With the discovery that drawn-wire tungsten could be coiled into concentrated filaments, further fields for miniature lamps were opened. Certain problems in the projection of light were materially simplified by the concentrated filament and because it was possible to get a greater length of wire in a small space, the high voltage, small bulb lamps of very much increased efficiency

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found their use in decorative fields. The introduction of an inert gas into certain types of these small lamps greatly increased their efficiency.

Following the increased demand came a study of the manufacture of these miniature lamps, a study which is constantly going on, and which is gradually taking them out of the class of hand made products. The difficulties encountered in cutting and mounting by hand a little piece of wire one third the diameter of a human hair and, say, 10 mm. in length can be more readily appreciated when it is known that 0.5 mm. in the length of filament in certain types of these lamps means about 5 per cent. difference in voltage. Thus it can be seen how a higher quality and comparatively low cost is obtainable with machine manufacture. A number of these miniature lamps now have their filaments coiled and cut by very accurate machines and a few have semi-automatically mounted filaments.

With the growing interest in miniature lamps came greater demands for their correct application to the fields involved. Where a few years ago almost any lamp which would give light would suffice, it is now demanded that light not only shall be produced economically, but that every detail of the lamp must be specially designed for the purpose. For instance, the dry cell hand-lantern first came on to the market with demands that all the light possible should be obtained from a single dry cell without regard for the life of lamp or battery. These lanterns have now settled down to replace the old oil lantern, and the manufacturers are requiring that the life of battery and lamp shall receive fully as much consideration as the light produced. In order to obtain a maximum amount of light throughout the life of a dry cell it became necessary to study their limitations. This involved study of current limitations, recuperation, the effect of heat, cold and dampness, and the ageing of cells while not in actual use.

Inasmuch as dry cells are coming to be used as the source of energy for small lamps in a great many fields, it will undoubtedly be of interest to study some of their characteristics.

One of the first questions that presented itself in this study was how to obtain data which would place all of the limiting char-

acteristics of dry cell operation on such a basis that the results would be comparable at all times. The Electro-chemical Society had at one time published a few suggestions on the subject, but as far as could be determined, nothing standard had been decided upon. After a number of tests under various conditions the following procedure was drafted and sent to the various large battery manufacturers with a request for their suggestions and criticisms and received their approval.

METHOD OF TESTING DRY CELLS WHEN DISCHARGING THROUGH MINIATURE TUNGSTEN LAMPS.

Class No. 1—Flashlight Batteries.
Class No. 2—Standard No. 6 Dry Cell Batteries.

General Instructions.

1—All tests are to be conducted at a temperature of not lower than 70° F. and as near thereto as possible. Actual temperature to be noted.

2—The current at rated volts is to be obtained on each lamp before start of test.

3—All lamps and tests are to be numbered.

4—At the completion of each test potential-time curves are to be plotted for all the data obtained. Besides the four curves obtained from the data taken on tests of standard No. 6 dry cell batteries, a curve is to be plotted which will be the average of the above four curves. In comparison tests the same scale is to be used for all curves.

5—The open circuit or recuperating periods are to be not less than two hours and shall be a fixed period of time for each test. The last period each day as well as the last period each week-end is to be noted.

6—Enough extra lamps of the same rating are to be on hand for each test in order to replace lamps immediately, should any burn out.

7—The voltmeter used is to have an electrical resistance of approximately 100 ohms per volt and to be in circuit only when readings are taken.

8—The electrical resistance of the wires between lamps and batteries must not exceed 0.0025 ohm per cell. (This is approximately the resistance of 1 foot of No. 14 B-S gauge copper wire.)

Class No. 1—Flashlight Batteries.

The battery cells shall be soldered together by means of copper wires in order to insure good connections between cells.

The following data should be obtained:

1—Initial open circuit voltage at start of test only.

2—Initial closed circuit voltage at start of test only.

3—The voltage at the end of the 1st, 3rd and 7th periods of burning. The voltage at the end of every 7th period thereafter.

Each period is to be of five minutes duration, with four periods per day.

The life of the battery is to be considered ended when the potential drops to 0.5 volt per cell.

In plotting curves, time shall be stated in minutes.

CLASS NO. 2—STANDARD NO 6 DRY CELL BATTERIES.

The following data should be obtained:

1—Initial open circuit voltage at start of test only.

2—Voltage readings during the 1st, 3rd and 5th periods of burning and during every 5th period thereafter.

There shall be four periods per day.

The duration of each period shall be as follows:

	Duration of period
Less than 0.3 watt per cell	1 hour
0.3 to 0.5 watt (inclusive) per cell	30 minutes
0.5 to 1.3 watts (inclusive) per cell	15 minutes
1.3 watts or more per cell	5 minutes

The following voltage readings are to be taken:

Duration of period	Readings
1 hour	[1]Initial closed circuit End of 20 minutes End of 40 minutes End of period
30 minutes	[1]Initial closed circuit End of 10 minutes End of 20 minutes End of period
15 minutes	[1]Initial closed circuit End of 5 minutes End of 10 minutes End of period
5 minutes	[1]Initial closed circuit End of 1 minute End of 3 minutes End of period

The life of the battery is to be considered ended when the potential of each cell drops to 0.7 volt.

In plotting curves time shall be stated in hours.

A typical discharge curve of two dry cells in series plotted from data taken in accordance with the above outline is shown in Fig. 1. The average curve is plotted as the average of the points on the

[1] This reading to be taken after needle has come to apparent rest.

other three curves and is the curve for which lamps must be designed to operate most efficiently. It must be understood that this curve is actually a series of cycles of discharges and recuperations. The start and completion of such a cyclic curve is shown in Fig. 2 and was obtained by means of a recording voltmeter with a special scale. It is interesting to note the difference between these cycles as shown in Fig. 3. These particular curves show the difference between the first and fourth cycle and bring out the point that initial closed circuit readings are of little value. Fig. 4 shows a

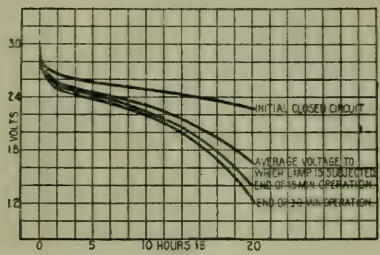

Fig. 1.—Typical voltage discharge curve of dry cells. (Three batteries; two dry cells in series.)

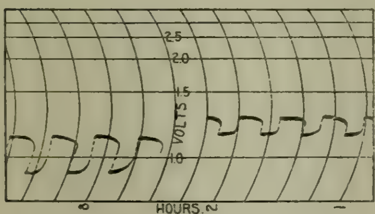

Fig. 2.—Chart of voltage variation of dry cells at start and completion of discharge.

cycle at the end of the life of the two cells shown in Fig. 1 and shows why it is not economical to use these cells after their potential has dropped to 0.7 volt per cell. It will be noted that the voltage starts at 2.2 volts and drops in one minute to 1.4 volts which is only 50 per cent. voltage of the battery and would consequently give little light. The curve continues on down to 0.2 volt, and this cycle will be repeated for several hours, but the abscissa in hours would continually decrease, thereby shortening the period of efficient light production to a matter of seconds. It

has been shown by numerous tests that after two hours recuperation of the cell there is no appreciable increase in power. Fig. 12 curve A, shows the marked effect of low temperature. This curve was obtained from a test of five cells in series operating at a temperature of about 22° F. After twenty hours the battery was placed in a temperature of about 70° F. and, as curve B shows, it increased in voltage while discharging until it nearly reached the normal operating voltage for that period in its life. It has been stated that a drop of 5° in temperature below 70° decreases the

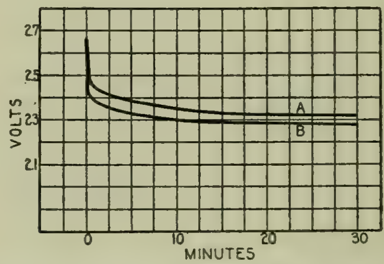

Fig. 3.—Voltage variation between first and fourth periods of discharge. A, variation in first period; B, variation in fourth period.

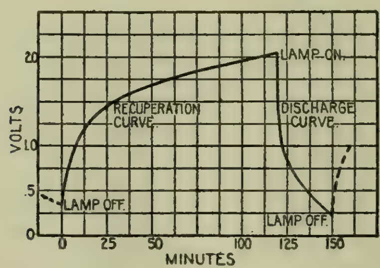

Fig. 4.—Cyclic variation of voltage for one period of discharge and recuperation. Two dry cells in series; variation during one complete period.

current by one ampere. However, this does not reduce the capacity of the battery if the latter is brought back to a temperature of 70° F., as shown by the previous curve. It will be seen that the two curves in Fig. 12 do not quite come together after the cold battery had been brought up to the temperature of the one operating under normal conditions. This may be explained by the fact that this battery was subjected to a certain amount of moisture. Moisture permanently reduces the capacity of a cell.

There are a great many uses for small lamps using dry cells as a source of energy, chief among which is the dry cell hand lantern. A number of different types of these lanterns are shown in Fig. 5. Lamps of this type are used by watchmen, campers, firemen and farmers.

The reflector design for hand lanterns has become quite important. At first the manufacturers wanted all the light possible in one direction and consequently used a polished parabolic reflector which was practically useless for any other purpose than to see comparatively great distances ahead. This did very well for watchmen, or hunters and campers, but was almost useless around the home or on the farm. Reflectors are now being scientifically designed to meet the demand for a more distributed light.

Another use for dry cell lighting coming into prominence is the lighting of summer cottages or permanent camps where a great deal of light is not needed. The convenience of having a little light is considered well worth the small expense of such an installation.

An interesting example of what can be accomplished by applying a little engineering knowledge to a comparatively simple, but nevertheless ingenious device, is that of an egg tester recently equipped with miniature lamps and proper reflectors. The original model of this device was equipped with one 6-volt, 0.84 ampere miniature lamp, using four No. 6 dry cells as a source of energy and having a piece of tin as a reflector (Figs. 9 and 9a). Two small parabolic reflectors were designed and recommended to be placed one behind each opening and to contain 6-volt, 0.35 ampere lamps. These reflectors and the distribution obtained are shown in Figs. 8 and 8a. It will be seen that the maximum light is directed through the egg and not to one side. As a direct result of these recommendations, the battery life was increased 400 per cent., the effective light flux was increased 300 per cent., and the number of eggs candled per battery increased 400 per cent.

Among other novelties using flashlight lamps are a fishing bobber, shown in Fig. 6; luminous fish bait, where a small lamp with a dry cell as a source of energy is placed in the "tail" of the bait, for night or early morning fishing. In the industrial field a good example of the use of these small lamps is an office signal

system (Fig. 10), not in wide use, but of great convenience. This system is so arranged with small lamps that the executive may place a call for any of his assistants and know by the signal on his desk whether or not his call is receiving attention.

In the professional field there are a great many uses for these small lamps. The retinascope, a small instrument for throwing an intense beam of light into the pupil of the eye, using a dry cell as a source of energy, is coming into use among doctors for eye examination. There are numerous other small devices on this same principle, such as a cycstoscope for internal diagnosis, dentists' mouth mirrors with a lamp and battery attached to the handle, and various devices for eye, ear and nose examination where, under usual conditions, proper seeing is difficult.

The class of lamps commonly known as automobile lamps and their application to automobile lighting is so well-known that it is hardly necessary to discuss them here. These same lamps, however, are being used for motor boat lighting and in some cases utilize the same sources of power as are used on automobiles. A very simple and effective method of lighting motor boats is with dry cells. A battery of twelve dry cells connected in series-multiple to obtain an average voltage of 3.5 volts, is used as a source of energy and has such a capacity that it is possible with care, to use the port and starboard lights, two riding lights and thirteen cabin, galley and stateroom lamps with one set of batteries per season. For this purpose 3.5-volt, 0.42-ampere lamps operating at an efficiency of 1.25 w. p. c. are used. A complete outfit is shown in Fig. 7.

Probably the best example of exacting conditions imposed upon these small lamps now as compared to the consideration given them a few years ago is that of the miner's lamp. This subject has previously been discussed before this society so that great detail is not necessary. The conditions imposed upon the lamp were that they should have a uniform life of 200 or 300 hours depending upon the source of energy, not more than 5 per cent. giving a life less than 250 or 170 hours, respectively. The second condition imposed was that at no time during the life of the lamp and a twelve-hour discharge of the battery should the amount of

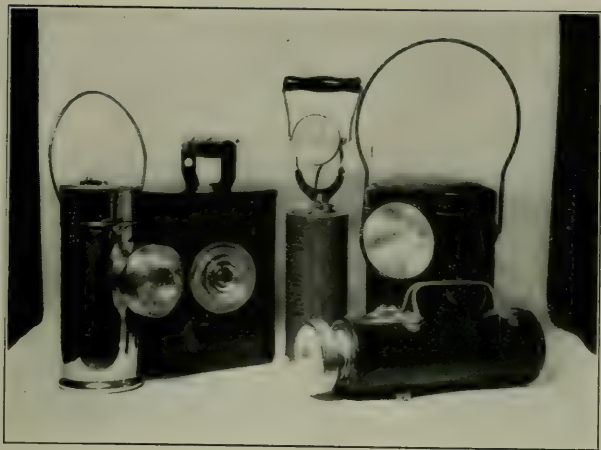

Fig. 5.—Typical dry cell hand lanterns.

Fig. 6.—Fishing bobber.

Fig. 7.—Motor boat lighting equipment.

Fig. 8.—Suggested reflectors for egg tester.

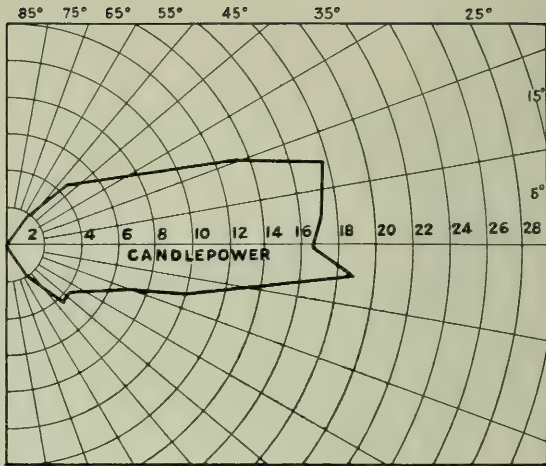

Fig. 8a.

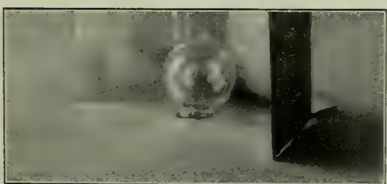

Fig. 9.

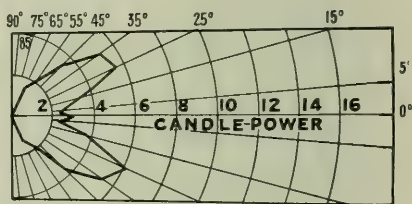

Fig. 9a.

Fig. 10.—An office signal system.

light fall below 1.5 lumens. The third condition imposed was that the uniformity of current and candlepower should meet fairly close conditions. To meet these meant careful reflector design and study of the battery discharge curves so that the most efficient lamp would be designed for this service.

The first step in this design was to obtain an average potential-time-discharge curve for a number of batteries discharging through lamps of such current rating that they would discharge the battery to its most economical voltage in the allotted time. Such a typical curve (A) is shown in Fig. 11. By means of an exponential equation involving lamp life with applied voltage, curve C, Fig. 11, was plotted. From this curve it is possible to ascertain the life of a lamp when burned at any voltage on

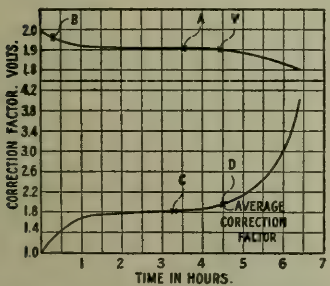

Fig. 11.—Typical voltage discharge of miner's lamp battery.

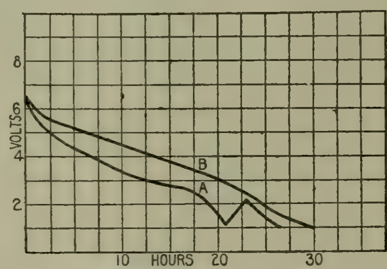

Fig. 12.—Effect of low temperature on voltage discharge of dry cells.

curve A. For example, if a lamp is designed for 300 hours life at 2 volts, in order to determine its life at 1.9 volts, it is only necessary to find 1.9 volts on curve A and the corresponding point on curve C. This gives a correction factor which when multiplied by 300 will give the life at 1.9 volts. The average ordinate D of this curve gives the voltage V′ for which a lamp may be designed to have the same life as when burned on the potential-time curve A. The obtaining of this voltage is most important since the life of incandescent lamps is an inverse function of voltage.

Inasmuch as the requirements were so drawn up as to combine the reflector with the lamp, it was necessary to take up the question of reflector design. The reflector engineers were held to the angle of the beam of light, and also the distribution across the

beam. Fig. 14 shows the theoretical minimum allowable distribution of illumination on a plain surface 20 in. (0.58 m.) from a reflector as required by the Bureau of Mines. From this distribution, it was a comparatively simple matter to plot a curve showing the distribution of light from a reflector which would give this distribution of illumination. This curve is shown in Fig. 13. From this curve it was necessary to obtain the shape of the reflector which would give the required distribution of illumination

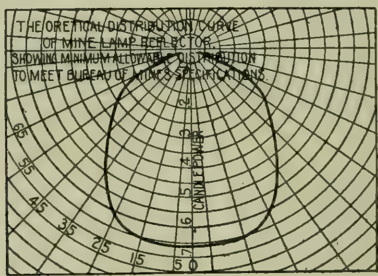

Fig. 13.—Distribution curve of mine lamp reflector to meet Bureau of Mines specifications.

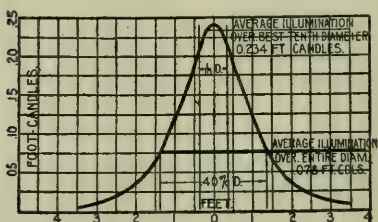

Fig. 14.—Minimum distribution of illumination to meet Bureau of Mines specifications for miner's lamps. (Theoretical distribution across a 7-ft. circle.)

over the circle specified. In Fig. 15 is shown one shape of reflector which will give a distribution closely approximating that required. The finish of the reflector must give an illuminated area which will answer the requirements that when "observed[2] with the eye there shall be no black spots within the 7-foot circle or any sharply contrasting areas of bright and faint illumination

[2] Procedure for establishing a list of permissible Portable Electric Mine Lamps. Schedule 6A, Dept. of Interior, *Bureau of Mines*.

anywhere." Two finishes have been used, porcelain enamel and aluminum. With a knowledge of the efficiency of these finishes and the volume of light required from a reflector, the amount of light the lamp would have to give was determined, including factors of safety, since the foregoing are minimum values. After determining this amount of light, and transferring it into a value of candlepower, the final step was to combine this candlepower with the voltage and current before determined and to obtain the efficiency of the lamp. This efficiency had to be such as to give the required life. With the above data, it was possible to design lamps to give the maximum amount of light under the conditions laid down.

All the foregoing details are mentioned to show that in small lamps a careful study of voltage conditions, reflector design, and

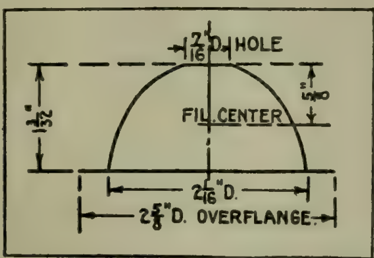

Fig. 15.—Experimental mine lamp reflector.

the requirements of the device using these small lamps is becoming more necessary as the uses of these lamps increase. Opposed to the old idea that small lamps were mere playthings is the growing tendency to expect them to do even more than should be expected from them. Uniformity of performance, as judged from experience with large lamps, is very difficult to obtain, for small lamps are generally of low voltage and high current. The accuracy of manufacture nesessarily is not as good and the difficulty in supplying the proper voltage at the lamp terminals is great. The regulation of the sources of energy used is not the best and each small voltage drop in wires or contacts is a considerable percentage of the total. Also, for the same efficiency, the life is only one tenth to one third of that of the large lamps,

and on account of the types of bases used the allowable current is limited. A careful consideration of these small lamps will show that they should receive at least as much attention as the large lamps where they are to be applied to important fields of illumination.

DISCUSSION

MR. L. C. PORTER: The number of uses to which miniature lamps are being put is almost infinite and almost every day sees new devices and new ways of using them. It is a very wide field and one which is rapidly increasing. The lamps are used for all sorts of spectacular efforts, in theatrical work especially, and since the beginning of the European War there has been a great demand for miniature lamps for hand lanterns used in the trenches. A number of interesting applications have been brought about by this war. Small lamps are used for signaling and a large number of these signal outfits are being sold. The lamps and reflectors are held in hand and used for signal purposes both at night and day.

Stereopticon and small moving picture machines for home use is another field for the lamps. The railroads are using a considerable number for position light signals; the medical and dental professions use large quantities. In fact, the miniature lamp business is growing more rapidly than that of regular lamps.

CODE OF LIGHTING.

Below is a prefatory note which was omitted from the Code of Lighting that appeared in the November 20, 1915, Vol. X, No. 8, issue of the TRANSACTIONS, beginning on page 605.

The Code, which was prepared jointly by the Committee on Factory Lighting and the Committee on Lighting Legislation, was presented at the Ninth Annual Convention held in Washington, D. C., Sept. 20-23, 1915. The Code has been accepted by the Council and is issued in separate pamphlet form by the Society.

PREFACE.

The following Code of Lighting for Factories, Mills and other Work Places, has been prepared by committees of the Illuminating Engineering Society in order to make available authoritative information for legislative bodies, factory boards, public service commissions and others who are interested in enactments, rules and regulations for better lighting.

While the code is intended as an aid to industrial commissions and other similar bodies in those states and municipalities which shall actively take up the questions of legislation as related to factory and mill lighting, it is intended in equal measure for the industries themselves as a practical working guide in individual efforts to improve lighting conditions. The language of the code has not been drafted according to legal phraseology but is simple and pointed throughout, thus being readily available for transforming into legal orders, and at the same time as a working guide in practical design and installation work.

REPORT OF THE CHAIRMAN OF THE COMMITTEE ON LIGHTING LEGISLATION.*

During the early part of the past year the Committee on Lighting Legislation made a general survey of the state laws relating to lighting in the United States and prepared a transcript (taken from the statute books) of the laws relating to lighting in the states of New York, Pennsylvania, Connecticut, Illinois and Wisconsin.

The study of these laws led to the conclusion that with few exceptions existing state lighting legislation is crude, fragmentary and often meaningless.

It was suggested that this committee frame a model lighting law to serve as a guide to legislators contemplating the enactment or amendement of laws pertaining to lighting. The difficulties in the way of framing a model law applicable to all classes of lighting are apparent and the committee decided to confine its work for the present to formulating a code of lighting for factories, mills and other places and a code of lighting for school houses.

Accordingly a special committee on factory lighting and a special committee on school lighting submitted to the Committee on Lighting Legislation technical data and rules upon which to base a lighting code.

A large part of the attention of the Committee on Lighting Legislation has been devoted for the past six months to the consideration of a comprehensive report of the Factory Lighting Committee, of which Prof. C. E. Clewell is chairman, containing material upon which was based the Code of Lighting now placed before you.

The purpose of the code is primarily to provide legislators with material upon which to base laws, rules and regulations relating to the lighting of factories, mills and other work places, but the Code is intended also to serve as a guide to factory managers and others in remodeling the lighting of existing buildings and in planning the lighting of new buildings.

Although much of the material offered is concrete and directly serviceable in the design of lighting installations, the Articles are

* Read at the convention of the Society at Washington, D. C., Sept. 20, 1915.

necessarily more or less general depending upon the limitations imposed by the present state of the art of lighting.

The committees have had the advantage not only of constructive criticism from their own combined membership of fifteen, including a legal representative skilled in legislatve work, but also from a considerable number of industrialists and factory managers connected with some of the leading manufacturing companies and institutions in the country.

The Code is to be published in separate pamphlet form with cover and is to have an index which is now being prepared.

Committee on Lighting Legislation.

L. B. MARKS, *Chairman,*
O. H. BASQUIN,
C. O. BOND,
C. E. CLEWELL,
O. H. FOGG,
C. L. LAW,
M. LUCKIESH,
F. J. MILLER,
G. H. STICKNEY,
L. A. TANZER,
W. H. TOLMAN.

Committee on Factory Lighting.

C. E. CLEWELL, *Chairman,*
W. A. D. EVANS,
T. J. LITLE, JR.,
D. M. PETTY,
R. E. SIMPSON.

ERRATUM.

The accompanying table of data was inadvertently omitted from the paper entitled "Present Practise in the Lighting of Armories and Gymnasiums with Tungsten Filament Lamps," by A. L. Powell and A. B. Oday, which appeared in the November 20, 1915, issue (vol., No. 8, pp. 746-759) of the TRANSACTIONS.

(NOTE.—This table is to aament Lamps," by A. L. Powell and A. B.
ONS.)

EQUIPMENT.

Regiment	Location	Di si in	Arrangement of lamps	Height of lamps in feet	Balcony	
Infantry— 7th N. G. N. Y. .	New York City	186	taggered 5 rows	Side rows 40 Centre row 45	19 ft. wide. 25-w., round bulb, all frosted lamps. In white bowl refls. Set flush with ceiling. 10-ft. centers.	Fig. 1
71st N. G. N. Y. .	New York City	155	egularly n 3 rows	30	On side walls under and above balcony. Bracket fixtures on 16' centers. Prismatic enclosing globes. Two 25-watt	Fig. 2

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The accompanying table of data was inadvertently omitted from the paper entitled "Present Practise in the Lighting of Armories and Gymnasiums with Tungsten Filament Lamps," by A. L. Powell and A. B. Oday, which appeared in the November 20, 1915, issue (vol., No. 8, pp. 746-759) of the TRANSACTIONS.

ERRATA.

Page 1151.—Text; third line from bottom, omit word "observation."

Page 1158.—Seventh line from top; substitute the words "the comparison" for "it."

Page 1158.—Delete late sentence of the first paragraph.

Page 1158.—Second paragraph, ninth line; words, 'is nothing more or less than a space threshold' should be 'is nothing more or less than the judgment of a space threshold.'

Page 1165.—Delete the second sentence reading, 'In the treatment of this point Dr. Cobb's discussion indicates his viewpoint.'

Page 1165.—Line 21, words 'have not a sufficient comprehension,' should be 'have only a minimum comprehension.'

Page 1168.—Fourteenth line from bottom word 'observation' should be 'notice.'

[The sentences deleted above were not the author's.]

(NOTE.—This table is to a ament Lamps," by A. L. Powell and A. B.
ONS.)

EQUIPMENT.

Regiment	Location	Di si in	Arrange- ment of lamps	Height of lamps in feet	Balcony	
Infantry— 7th N. G. N. Y. .	New York City	186	taggered 5 rows	Side rows 40 Centre row 45	19 ft. wide. 25-w., round bulb, all frosted lamps. In white bowl refls. Set flush with ceiling. 10-ft. centers.	Fig. 1
71st N. G. N. Y. .	New York City	155	egularly n 3 rows	30	On side walls under and above balcony. Bracket fixtures on 16' centers. Prismatic enclosing globes. Two 25-watt each globe.	Fig. 2
69th N. G. N. Y. .	New York City	202	taggered 5 rows	25	11 ft. wide. Below 200-watt lamps. Prismatic bowl reflectors on 34-ft. centers.	
12th N. G. N. Y. .	New York City	200	egularly 3 rows	30	Gas below and above balcony for emergency.	
1st N. G. N. J. .	Newark, N. J.	250	egularly 4 rows	20	Balcony narrow.	
47th N. G. N. Y., small shed . .	Brooklyn	130	taggered 3 rows	32		
23rd N. G. N. Y. .	Brooklyn	200	egularly 3 rows	35		
State Armory .	Schenectady, N. Y.	130	egularly 3 rows	—		
State Armory .	Albany, N. Y.	240	taggered 5 rows	Outside 20 Center 25		
Coast Defence— th N. G. N. Y. .	New York City	180	egularly 2 rows	35	No balcony.	

(NOTE.—This table is to accompany a paper entitled "Present Practise in the Lighting of Armories and Gymnasiums with Tungsten Filament Lamps," by A. L. Powell and A. B. Oday, which appeared on pp. 746–759 of vol. X, No. 8 (November 20, 1915) issue of the TRANSACTIONS.)

APPENDIX I.—ILLUMINATION DATA ON ARMORIES LIGHTED WITH VARIOUS TYPES OF MODERN EQUIPMENT.

Regiment	Location	Dimensions in feet	Area in sq. ft	Height to peak in feet	Color of walls	Color of roof	Color of floor	Number of lamps	Size of lamps in watts	Total watts	Watts sq. ft. Actual	Watts sq. ft. Comparative†	Type of Reflector	Type of Fixture	Arrangement of lamps	Height of lamps in feet	Balcony	
Infantry—																		
7th N. G. N. Y.	New York City	186 x 276	51,000	90	Green	Green	Light wood	28	1,000 clear	28,000	0.55	0.92	Prismatic enclosing unit. Clear bowl reflector with etched prismatic dish over mouth. 17" dia., 20 1/8" high.[1]	Steel cable	Staggered [illegible] rows	Side rows 40 Centre row 45	19 ft. wide. 25-w., round bulb, all frosted lamps. In white bowl refls. set flush with ceiling. 10-ft. centers.	Fig. 1
71st N. G. N. Y.	New York City	155 x 155	24,000	50	Brick	Gray	Light wood	24	500 b. f.	12,000	0.50	0.72	Pressed prismatic bowl refls., 14 1/2" dia., 8 1/2" high.[2]	2 arm fixtures 6' spread	Regularly [illegible] rows	30	On side walls under and above balcony. Bracket fixtures on 16' centers. Prismatic enclosing globes. Two 25-watt each globe.	Fig. 2
69th N. G. N. Y.	New York City	232 x [illegible]	38,200	100	Brick, white wainscoting	Gray	Med. wood	48	400 b. f.	19,200	0.50	0.72	Pressed prismatic bowl refls., 14 1/2" dia., 8 1/2" high.[2]	2 light ring fixtures	Staggered [illegible] rows	25	11 ft. wide. Below 250-watt lamps. Prismatic bowl reflectors on 34-ft. centers.	
12th N. G. N. Y.	New York City	200 x 180	36,000	50	Dark oak	Dark	Dark wood	36	300 b. f.	10,800	0.30	0.43	Pressed prismatic bowl refls., 11 1/2" dia., 7 1/2" high.[4]	4 arm fixtures	Regularly [illegible] rows	20	Gas below and above balcony for emergency.	
1st N. G. N. J.	Newark, N. J.	250 x 140	35,000	60	Buff	Buff	Med. wood	32	400 clear	12,800	0.37	0.41	12" flat white glass reflector.	Combination gas and elec.	Regularly [illegible] rows	20	Balcony narrow.	
47th N. G. N. Y., small shed	Brooklyn	130 x 200	26,000	40	Blue	Dark	Loam*	8	750 clear	6,000	0.23	0.36	Opalescent enclosing globes. 12" dia. with ventilated holder.[4]	Steel cable	Staggered rows	32		
23rd N. G. N. Y.	Brooklyn	200 x 300	60,000	75	Cream	Oak	Med. wood	15	1,000 b. f.	15,000	0.25	0.42	Deep bowl, dense opal refl. 16" dia., 9" deep, mogul socket and skeleton holder.[6]	Steel cable	Regularly rows	35		
State Armory	Schenectady, N. Y.	130 x 85	11,000	—	—	—	—	48	100 b. f. vacuum	4,800	0.44	0.40	Pressed prismatic bowl refl., 8 3/4" dia., 5 1/4" deep.[6]	4 arm fixture	Regularly rows	—		
State Armory	Albany, N. Y.	240 x 175	42,000	45	Cream	Pine	Dark wood	26	750 clear	19,500	0.46	0.71	20" enameled steel refl. and 12" opalescent enclosing globe.[7]	2 arm fixture	Staggered [illegible] rows	Outside 20 Center 25		
Coast Defence—																		
8th N. G. N. Y.	New York City	180 x 170	30,500	70	White	Gray	Light wood	8	1,000 clear	8,000	0.26	0.44	Light opalescent enclosing globe, 12" dia. ventilated copper casing around socket. 30" over all.[8]	Steel cable	Regularly [illegible] rows	35	No balcony.	
9th N. G. N. Y.	New York City	[illegible] x 188	[illegible]	60	Cream	Dark	Med. wood	14 / 20	750 cl. / 200 b. f.	14,500	0.28	0.43	Deep bowl porcelain enameled steel reflectors 17" dia.[9]	Steel cable	Regularly [illegible] rows	40	200-watt under balcony with prismatic reflectors.	
13th N. G. N. Y.	Brooklyn	[illegible]	[illegible]	80	Cream	Pine, dark iron-work	Light wood	16 / 16	750 b. f. / 1,000 b. f.	28,000	0.43	0.69	Deep bowl dense opal refl., 16" dia., 9" deep, mogul socket and skeleton holder.[5]	Steel cable	Regularly [illegible] rows	Side rows 35 Center rows 60		
Field Artillery—																		
1st N. G. N. Y.	New York City	228 x 175	[illegible]	45	Dark wood	Very dark	Brown loam	24	500 clear	12,000	0.30	0.43	18" enameled steel refl., ventilated holder and 8" opalescent globe around lamp.[10]	Steel cable	Regularly [illegible] rows	30		
2nd Battery, N. G. N. Y.	New York City	288 x [illegible]	47,[illegible]00	50	Dark wood	Dark	Brown loam	27	500 clear	13,500	0.28	0.40	18" enameled steel refl., ventilated holder and 8" opalescent globe around lamp.[10]	Steel cable	Staggered [illegible] rows	32		
3rd Battery, N. G. N. Y.	Brooklyn	125 x 175	22,000	58	Light blue	Nat wood	Black tan bark	12	1,000 b. f.	12,000	0.55	0.[illegible]	Deep bowl dense opal refl., 16" dia., 9" deep, mogul socket and skeleton holder.[5]	Steel cable	Regularly [illegible] rows	24		
Cavalry—																		
Squadron A	New York City	100 x [illegible]	15,000	50	White	Buff	Tan bark	8	500 clear	4,000	0.27	0.39	18" enameled steel refl., ventilated holder and 8" opalescent globe around lamp.[10]	Steel cable	Regularly [illegible] rows	30		
Troop C	Brooklyn	175 x 310	54,000	70	Cream	Cream	White sand, shavings and loam	30	750 clear	22,500	0.42	0.65	Deep bowl dense opal refl., 16" dia., 9" deep, mogul socket and skeleton holder.[5]	Steel cable	Staggered rows	35		Fig. 3
Engineer Corps—																		
22nd N. G. N. Y.	New York City	[illegible] x 175	67,000	70	Brick	Light green	Pine	21	1,000 b. f.	21,000	0.31	0.52	Deep bowl porcelain enameled steel refl., 17" dia.[9]	Steel cable	Regularly 3 rows	45	Balcony 14 ft. wide, 10 1/2 ft. high.	
Signal Corp—																		
2nd Signal corp.	Brooklyn	78 x 92	7,000	45	Cream, brown wainscoting	Varnished oak	Med. wood	5	500 b. f.	2,500	0.36	0.52	Deep bowl dense opal refl., 16" dia., 9" deep, mogul socket and skeleton holder.[5]	Steel cable	Symmetrical	25		Fig. 4
Naval—																		
2nd Naval Bat., N. G. N. Y.	Brooklyn	157 x 2[illegible]	47,000	75	Cream	Oak dark iron-work	Pine wood	18	750 b. f.	13,500	0.29	0.45	Deep bowl dense opal refl., 16" dia., 9" deep, mogul socket and skeleton holder.[5]	Steel cable	Staggered 4 rows	32 1/2		
U.S. Naval Acad.	Annapolis	100 x 400	40,000	70	Brick	Dark wood	Light wood	18	1,000 clear	18,000	0.45	0.75	20" enameled steel refl. and 12" spherical enclosing globe.[11]	Steel cable	Staggered 3 rows	45		Fig. 5
							(To give some idea of the older practise the following data are appended.)											
47th N. G. N. Y., large shed	Brooklyn	200 x 300	60,000	85	Tan	Wood	Wood	720	40 clear	28,800	0.48	0.46	24 Corona combination gas and electric fixtures: 15 gas and 30 electric each.	—	Regularly 3 rows	Outside 25 center 30		
14th N. G. N. Y.	Brooklyn	260 x 196	51,000	85	Cream	Blue	Wood	900	40 clear	36,000	0.70	0.67	30 Corona combination gas and electric fixtures: 15 gas and 30 electric each.	—	Regularly 3 rows	Outside 24 center 31		

* For trench digging. † Equivalent with lamps at 10 lumens per watt.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 1, 1915

PART II

Miscellaneous Notes

Council Notes.

A meeting of the Council was held January 14 in the general offices of the Society, 29 West 39th Street, New York, N. Y. Those present were: A. S. McAllister, president; E. M. Alger, C. O. Bond, H. Calvert, Ward Harrison, George A. Hoadley, C. A. Littlefield, general secretary; L. B. Marks, Preston S. Millar, A. S. Miller, J. Arnold Norcross, A. L. Powell, representing G. H. Stickney, vice-president and chairman of the Committee on papers. Upon invitation: M. Luckiesh, chairman of the School Lighting Committee; A. Hertz, chairman of the Finance Committee; and Norman Macbeth, chairman of the New York Section.

The Finance Committee submitted an oral report on the total expenses and receipts for the first three months of the present fiscal year compared with the corresponding period of the last year. Upon recommendation of the committee the Council authorized the payment of vouchers No. 1943 to No. 1976 inclusive, aggregating $1,919.91.

A written progress report was received from the Time and Place Committee (1915 Convention). The report indicated that of the places under consideration, Washington, D. C. was the one most favored.

An oral report was given by Ward Harrison on behalf of Mr. W. M. Skiff, chairman of the 1914 Convention Committee.

Reports on section activities were received from F. A. Vaughn, vice-president of the Chicago Section; A. L. Powell for G. H. Stickney, vice-president of the New York Section; Ward Harrison, vice-president of the Pittsburgh Section; and George A. Hoadley, vice-president of the Philadelphia Section.

Mr. C. O. Bond reported orally on a proposal that the Philadelphia Section become affiliated, along with the local sections of other engineering societies, with the Engineers' Society of Philadelphia. It was resolved that, if the Philadelphia Section desires to join the movement, the Council will be disposed to consider the proposal favorably, provided the expense is not too great.

Mr. M. Luckiesh gave an oral report on behalf of the Committee on School Lighting and submitted the manuscript of a lecture entitled, "Safe-Guarding the Eyesight of Children." It was resolved that, after the manuscript had passed through the usual publication channels, the lecture be published; and that the committee announce the fact that the lecture is to be available for those interested in the subject of school lighting.

A written report was received from the Committee on Glare from Reflecting Surfaces, giving data on the results of tests made on the so-called "window" envelopes. It was voted that the report be returned to the committee with a request that the last paragraph be revised as indicated, and that the title be so worded as to indicate that these envelopes had passed through the mails and were submitted for test by a letter carriers' association.

The appointment of the following *Committee on Remodeling the Lighting of the General Offices* was confirmed: H. E. Ives, chairman; Clarence L. Law, Thos. W. Scofield; L. B. Marks and George W. Cassidy, advisory members.

A written report was received from the Committee on Remodeling the Lighting of the General Offices. It was

voted that the Committee be requested to proceed with a temporary installation, as outlined in the committee's report, in order that it may be tried out by the Council at its meetings.

The following additional committee appointments were confirmed:

Committee on Factory Lighting: C. E. Clewell, chairman; W. A. D. Evans, T. J. Litle, Jr., R. E. Simpson and G. H. Stickney.

Committee on Popular Lectures: C. F. Scott.

Committee on Constitutional Revision: W. D. Weaver, chairman; Louis Bell, L. B. Marks, and C. H. Sharp.

The resignation of the following committee members were accepted with regret:

Dr. H. E. Ives from the Committees on Research, Popular Lectures, and Lighting Legislation. Dr. Alexander Duane from the Committee on Papers.

An invitation from the trustees and faculty of the University of North Carolina to appoint a representative to attend the inauguration of Mr. William Kidder Graham as president of the university was received. President McAllister was empowered to appoint a representative.

A proposal to create a class of members to be known as fellows was tabled for the next meeting of the Council. It was understood that copies of this proposal would be mailed to the members of Council for consideration in the meantime.

The following communication was received from Dr. C. H. Sharp, secretary of the United States National Committee of the International Commission on Illumination.

In the normal course of events this committee would be obliged at this time of the year to request from the Illuminating Engineering Society the regular annual contribution of $100 toward the expenses of the committee and toward the payment required by the International Commission on Illumination. Last year the commission was supported by the contributions of five countries, namely England, France, Germany, Italy and United States. The expenses of the commission were very small so that the honorary secretary has a substantial fund in the treasury, which on account of the temporary suspension of the activities of the commission is likely to be but little encroached upon. This committee, therefore, makes no call on you at this time for any further funds. The expectation is, however, that at the close of the war the International Commission on Illumination will again become active and the regular contribution will be required.

The following resolution submitted by the Committee on Editing and Publication was adopted:

The Committee on Editing and Publication recommends that technical and trade journals be advised that the papers of the Society may be reprinted in whole or in part, subsequent to the dates of presentation, by any member of the technical or trade press, provided proper credit is given.

It was suggested by several members of the Council that all matters of routine business might be transacted by the Council Executive Committee previous to each council meeting.

Consideration of the outlines of work for the present year, submitted by committees, was deferred until the next meeting.

Section Activities.

CHICAGO SECTION

Prof. Morgan Brooks of the University of Illinois delivered a lecture on "Vision and Illumination" at a meeting of the Chicago Section in the rooms of the Western Society of Engineers, December 18, 1914. During his lecture Prof. Brooks described an instrument which he called a rapid illuminometer.

At a meeting held January 29, Dr. Clayton H. Sharp presented a paper

entitled "The Knowns and Unknowns of Physical Light."

The tentative program of papers for the Chicago Section for the season 1914-1915 is as follows:

February—Other Light Sources (Gas and Electric).

March—Decoration: Color Schemes; Fixture Forms; Use of Colored Sources.

April—Lighting of Small Interiors: Homes; Small Offices; Show Windows.

May—Lighting of Large Interiors: Churches; Halls; Large Offices.

June—Lighting of Open Air Spaces: Streets; Building Exteriors; Signs.

NEW ENGLAND SECTION

A meeting of the New England Section was held in the Engineers' Club on Friday, February 5. Mr. Munroe Rhodes Pevear of Boston gave a paper on "Three Color Illumination" which was illustrated by practical demonstrations. Mr. Pevear has made an exhaustive study of commercial methods for procuring light of any degree, intensity or color. The paper was accompanied by a number of demonstrations.

The programs of coming meetings will be announced later.

PHILADELPHIA SECTION

A meeting of the Philadelphia Section was held January 15 at the Engineers' Club, 1317 Spruce Street. Two papers were presented, one by Harry Markle on "The Lighting of Willow Grove Park," and the other on "Piping Houses for Gas Lighting" by Mr. H. R. Sterrett. Seventy-five members and guests were present.

The following program has been announced for the rest of the season:

February 8—Joint meeting with American Institute of Electrical Engineers. "A Year's Progress in Illumination" by Prof. Geo. A. Hoadley; "Recent Developments and Applications of Incandescent Lamps" by Geo. H. Stickney. Electric lamps will be exhibited.

February 19—"Scientific Management" by Frederick W. Taylor. A demonstration of the pathescope, a new moving picture device, will be given.

March 19—"A Method of Securing Uniformity of Reading of the Flicker Photometer with Different Observers" by Herbert E. Ives and E. F. Kingsbury. Photometric apparatus will be exhibited.

April 16—"The Problem of Lighting Design," by Prof. Arthur J. Rowland. This paper will include a discussion of the following items: Methods used for designing: (*a*) direct lighting (*b*) indirect lighting; difficulties and faults in the use of such methods; accuracy to be expected in the results accomplished; what constitutes good design. Exhibition of new types of lighting fixtures.

May 21—"Store Lighting" by W. R. Moulton. This meeting will be held in Baltimore, Md. The place will be announced later.

NEW YORK SECTION

The New York Section held a joint meeting with the Metropolitan Section of the Professional Photographers' Society of New York in the Engineering Societies Building, January 14. Two papers were presented: one "The Application of the Tungsten Lamp to Photography" by Mr. M. Luckiesh, physicist of Nela Research Laboratory, Cleveland, O.; the other "Gas Lamps for Photography" by Mr. R. F. Pierce of the Welsbach Company, Gloucester, N. J. The papers were discussed by representatives of both societies. Mr. J. E. Williamson gave a short talk on "Submarine Photography," which was accompanied by lantern slides.

The tentative program for the New

York Section for the rest of the season is as follows:

February—"The Type C Lamp for Street Lighting" by Mr. W. H. Rolinson; "The Magnetite Lamp for Street Lighting" by Mr. C. A. B. Halvorson, Jr.

March—This meeting is to be arranged by the Fine Arts Committee of the Section. There will be a symposium on light by various artists, decorators and architects; each speaker is to have about ten minutes to explain the lighting needs of his profession.

April—Joint meeting of the New York sections of the Illuminating Engineering Society, the National Commercial Gas Association and the National Electric Light Association to discuss the commercial side of the good lighting propaganda. Addresses will be given by representatives of the three organizations.

May—To be announced later.

June—Dr. Hollis Godfrey of Philadelphia, Pa., has been invited to present a paper on "Good Lighting as an Aid to Welfare Work" to include a description of the work which he has done in the Metropolitan Life Insurance Building in New York.

PITTSBURGH SECTION

The Pittsburgh Section held a joint meeting with several engineering societies in Cleveland, O., January 29. A popular lecture entitled "Safeguarding the Eyes of School Children," accompanied by a series of lantern slides, was given by Mr. M. Luckiesh.

The program, as far as known, for the rest of the season is given below.

February 19—A popular lecture on "Home Lighting."

March 19—Joint meeting with the American Institute of Electrical Engineers. Paper: "Projector Lanterns and Searchlights" or "Incandescent Lamp Manufacture."

New Members

The following twenty-four applicants were elected members of the Society at a Council meeting held January 14:

ADAM, JOHN NEIL
New Business Assistant to Division Agent, Public Service Electric Co., 271 North Broad St., Elizabeth, N. J.

ANDREWS, WILLIAM S.
Consulting Engineering Department, General Electric Co., Schenectady, N. Y.

BUTLER, HENRY E.
Assistant to Illuminating Engineer, General Electric Co., Illuminating Engineering Laboratory, Schenectady, N. Y.

BILLAU, LEWIS S.
Assistant Electrical Engineer, Baltimore & Ohio Railway Co., Baltimore, Md.

EMERSON, HARRINGTON
Counseling Engineer on Efficiency, The Emerson Co., 30 Church St., New York, N. Y.

EMERSON GUY C.
Consulting Engineer for Municipal Works, Boston Finance Commission, 73 Bemont St., Boston, Mass.

FAUGHT, RAY C.
Local Supply Department (Manager) General Electric Co., 1217 Munsey Building, Baltimore, Md.

HEILMAN, D. B.
Electrical and Mechanical Engineer, Philadelphia & Reading Railway Co., Reading, Pa.

HOOVER, JOHN WALTER.
Supt. Lighting and Merchandise Sales, Gas Division, Consolidated Gas, Electric Light & Power Co. of Baltimore, Baltimore, Md.

HESS, WM. L.
Doctor, eye, ear, nose and throat, 400 California Building, Denver, Colo.

HEWITT, CONRAD
Supt. of the Building, Metropolitan Museum of Art, Fifth Avenue and 82nd St., New York, N. Y.

JONES, W. R.
Engineer of Construction, University of Penna. (Light & Heat Station), 3401 Spruce St., Philadelphia, Pa.

KINGSBURY, EDWIN F.
Laboratory Assistant, Physical Laboratory, United Gas Improvement Co., 3101 Passyunk Avenue, Philadelphia, Pa.

MOHR, WILLIAM
Supt. of Lamps and Lighting, Municipal Department, Room 8, City Hall, Baltimore, Md.

MCLAUGHLIN, JOHN C.
Chief Clerk, Potomac Elec. Power Co., 231 Fourteenth N. W., Washington, D. C.

MARSH, GEORGE EVERETT
Assistant Professor of Electrical Engineering, Armour Institute of Technology, Chicago, Ill.

MUNCY, VICTOR EMANUEL
Professor of Mechanics and Applied Electricity, Ohio Mechanics' Institute, Cincinnati, Ohio.

ORNER, ALBERT
Designer and Salesman of Lighting Fixtures, Consolidated Chandelier Co., 132 West 14th St., New York, N. Y.

PILLSBURY, CHARLES L.
Consulting Engineer 895 Metropolitan Life Building, Minneapolis, Minn.

PFEIFFER, BERNARD V.
Engineer, Nashville Gas & Heating Co., 611 Church St., Nashville, Tenn.

PLATT, CHARLES J., JR.
General Foreman, United Electric Light & Power Co., 130 East 15th St., New York, N. Y.

ROSENFELD, EUGENE I.
President & General Manager, Eugene I. Rosenfeld & Co., Inc., 8 S. Howard St., Baltimore, Md.

SIMONSON, G. METCALFE
Assistant Electrical Engineer, State Department of Engineering, Forum Building, Sacramento, Cal.

WILDER, STUART
Engineer, Electrical Dept., Westchester Lighting Co., 1st Avenue and 1st St., Mt. Vernon, N. Y.

Index for Volume IX.

The index for Volume IX (1914 TRANSACTIONS) is mailed with this issue.

NOTICE.

The Committee on Editing and Publication will be glad to publish in the TRANSACTIONS personals, obituaries, and such news items as are of interest to the members of the Society. All items of this sort should be addressed to the Illuminating Engineering Society, 29 West 39th Street, New York, N. Y.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 2, 1915

PART II

Miscellaneous Notes

Council Notes.

A meeting of the Council was held February 11 in the general offices of the Society, 29 West 39th Street, New York, N. Y. Those present were: A. S. McAllister, president; E. M. Alger, C. O. Bond, H. Calvert, P. W. Cobb, Ward Harrison, C. A. Littlefield, general secretary; L. B. Marks, treasurer; Preston S. Millar, Alten S. Miller, W. Cullen Morris, J. Arnold Norcross, G. H. Stickney. Upon invitation Mr. V. R. Lansingh.

Written reports on section activities were submitted by the following vice-presidents: Ward Harrison (Pittsburgh Section); George A. Hoadley (Philadelphia Section); G. H. Stickney (New York Section); and F. A. Vaughn (Chicago Section).

After a discussion of whether the Philadelphia Section of the I. E. S. should become an affiliated member of the Engineers' Society of Philadelphia, it was voted that the matter be laid upon the table.

Upon recommendation of the Finance Committee, the Council authorized the payment of vouchers Nos. 1977 to 2006 inclusive and Nos. 2008 to 2011 inclusive aggregating $1,050.01.

It was voted that the report of the Committee on Glare on window envelopes be published in the TRANSACTIONS subject to the usual publication procedure of the proper committees.

Mr. Preston S. Millar, chairman, reported orally for the Sustaining Membership Committee.

A written report of the Committee on Time and Place was read by Mr. G. H. Stickney, chairman. The committee recommended that the 1915 Convention be held in Washington, D. C., during the third or fourth week in September.

Committee appointments and changes: The resignation of Mr. Preston S. Millar from the Committee on Constitutional Revision was accepted.

The resignation of Mr. G. H. Stickney from the Committee on Factory Lighting was accepted.

The resignation of Dr. H. E. Ives as chairman of the Committee on Remodeling the Lighting of the General Offices was accepted with a vote of thanks from the Council.

Dr. C. H. Sharp was appointed secretary of the Committee on Constitutional Revision.

Prof. W. S. Franklin was appointed a member of the Committee on Popular Lectures.

Mr. H. Calvert submitted blue prints showing by curves the expenses and income of the Society from 1907 to 1914.

It was voted that the Committee on Constitutional Revision be requested to recommend (1) changes in the Constitution which would increase the dues of members to $10.00 and create an additional grade of members having dues of $5.00; (2) qualifications for membership in these two grades.

Section Activities.

CHICAGO SECTION

Nelson M. Blank, M. D., of Milwaukee, Wis., delivered a lecture on "A Resumé of the Physical, Physiological and Psychical Phases of Vision," at a meeting of the Chicago Section in the rooms of the Western Society of Engineers, February 25, 1915.

The tentative program of papers for the Chicago Section for the season 1914-1915 is as follows:

March—Decoration: Color Schemes; Fixture Forms; Use of Colored Sources.

April—Lighting of Small Interiors: Homes; Small Offices; Show Windows.

May—Lighting of Large Interiors: Churches; Halls; Large Offices.

June—Lighting of Open Air Spaces: Streets; Building Exteriors; Signs.

NEW ENGLAND SECTION

A meeting of the New England Section was held in the Engineers' Club, Boston, February 26. Three papers were presented: "Effects of Radiation on the Eye" by Dr. Louis Bell, "The Axial Chromatic Aberration of the Human Eye" by Dr. P. G. Nutting, and "How Faulty Illumination Injures the Eye" by Dr. Walter B. Lancaster.

The programs of coming meetings will be announced later.

NEW YORK SECTION

A meeting of the New York Section was held in the Engineering Societies Building, February 11. Mr. C. A. B. Halvorson presented a paper on "The Arc—Its Status as a Street Illuminant," which was accompanied by a demonstration of the effect of varying current and voltage at the arc, and a description of the possibilities of the various types of metallic flame arcs.

The tentative program for the New York Section for the rest of the season is as follows:

March—A paper by L. C. Porter and W. G. Gove on the lighting of the new cars of the New York Municipal Railway Corporation.

April—Joint meeting of the New York Section of the Illuminating Engineering Society, the National Commercial Gas Association, and the National Electric Light Association to discuss the commercial side of the good lighting propaganda.

May—To be announced later.

June—To be announced later.

PHILADELPHIA SECTION

The Philadelphia Section held a joint meeting with the American Institute of Electrical Engineers at the Engineers' Club, on February 8. Two papers were presented, one by George A. Hoadley on "A Year's Progress in Illumination," and the other on "Recent Developments and Applications of Incandescent Lamps" by George H. Stickney.

A meeting of the Philadelphia Section was held February 19 at the Engineers' Club, 1317 Spruce Street. Mr. Frederick W. Taylor presented a paper on "Scientific Management." A demonstration of the pathescope, a new moving picture device, was given.

The following program has been announced for the rest of the season:

March 19—"A Method of Securing Uniformity of Reading of the Flicker Photometer with Different Observers" by Herbert E. Ives and E. F. Kingsbury. Photometric apparatus will be exhibited.

April 16—"The Problem of Lighting Design," by Prof. Arthur J. Rowland. This paper will include a discussion of the following items: Methods used for designing: (*a*) direct lighting, (*b*) indirect lighting; difficulties and faults in the use of such methods; accuracy to be expected in the results accomplished; what constitutes good design. Exhibition of new types of lighting fixtures.

May 21—"Store Lighting" by W. R. Moulton. This meeting will be held in Baltimore, Md. The place will be announced later.

PITTSBURGH SECTION

The Pittsburgh Section held a meeting in Cleveland on January 29 at the Addison School, 79th and Hough Streets. Preceding the meeting an informal dinner was held at the University Club, following which there was

an inspection of several rooms in the Addison School, each of which was equipped with a different system of lighting fixtures. Two papers were presented, one, "Safeguarding the Eyesight of School Children," accompanied by a number of slides, was presented by Mr. Magdsick in the absence of the author, Mr. M. Luckiesh; and the other, "A Discussion of Present Practise in School Lighting" by Mr. E. B. Rowe. Interesting examples of school room lighting were shown by slides. Sixty members and guests, including members of the Board of Public Education and teachers, were present. This meeting indicates a broadening of the activities of the Society and represents an attempt to popularize good lighting through public education. The Section's efforts are directed toward the saving of eyesight, and no better place for this work is apparent than in the schools. Particular credit is due the authors of the papers for preparing good material, for their time and expense in preparing slides and illustrations, and for arranging the several different displays in the school rooms. The co-operation of the local Board of Education and the school authorities was given freely and appreciated.

The regular monthly meeting of the Pittsburgh Section, held February 19 at the Engineers' Society Auditorium, was preceded by a dinner at the Fort Pitt Hotel. Before the meeting the members and guests inspected several exhibition booths showing various lighting features. In a preliminary talk, Dr. Edward Stieren described by means of colored charts the structure of the human eye and its usual optical defects. Prof. Francis C. Caldwell of the Ohio State University presented a paper entitled "Illumination and Eye Fatigue." His subject included a general resumé of the methods used in measuring visual acuity, and a discussion of the results of the various investigators.

March 19—Joint meeting with the American Institute of Electrical Engineers. Paper: "Projector Lanterns and Searchlights" or "Incandescent Lamp Manufacture."

New Members.

The following twenty-three applicants were elected members of the Society at a Council meeting held February 11:

Acheson, Albert R.
Professor of Mechanical Engineering, Syracuse University; Consulting Engineer, Bureau of Gas and Electricity, City of Syracuse; Syracuse, N. Y.

Ball, Wm. J.
Secretary, Tri-City Electric Company, 1529 Third Ave., Moline, Ill.

Blakeslee, Doraf Wilmot
Assistant Professor of Electrical Engineering, University of Arkansas, Fayetteville, Ark.

Carpenter, C. A.
Electrical Engineer, Graham, Burnham & Co., 1417 Railway Exchange, Chicago, Ill.

Fleming, John P.
New Business Representative, The United Gas Improvement Co., 1035 Market St., Philadelphia, Pa.

Goldsmith, Lester M.
Testing and Designing Engineer, Perpetual Fuse Company, 1606 S. Fourth St., Philadelphia, Pa.

Gleason, Marshall T.
Gleason, Tiebout Glass Co., 99 Commercial St., Brooklyn, N. Y.

Gross, J. Harry
Park Engineer, Park Board, Druid Hill Park, Baltimore, Md.

HOWE, LUCIEN
Ophthalmologist, 520 Delaware Ave., Buffalo, N. Y.

HIRSCH, H. H.
President, Hirsch Electric Mine Lamp Company, 314 N. 12th St., Philadelphia, Pa.

KELLEY, J. B.
Salesman, Frank H. Stewart Electric Co., 37 N. 7th St., Philadelphia, Pa.

KOLLMORGEN, FREDERICK L. G.
Optical Expert, Keuffel & Esser Co., Adams St., Hoboken, N. J.

LIENESCH, WALTER H.
General Manager, Chicago Concrete Post Co., 608 S. Dearborn St., Chicago, Ill.

LEE, STANTON P.
Architect, 53 Third St., Troy, N. Y.

NORRIS, B. H.
Assistant to W. D'A. Ryan, General Electric Co., Illuminating Engineering Laboratory, Schenectady, N. Y.

PORTER, GEOFFREY
Assistant Chief Engineer, B. C. Electric Railway Co., Ltd., Canall St., Vancouver, B. C.

PINDELL, WM. H., JR.
Incandescent Lamp Salesman, Sterling Electric Lamp Division of General Electric Co., 313 Union Trust Bldg., Baltimore, Md.

RAMIREZ, CHARLES E.
Representative, Bayley & Sons, Inc., 101 Park Ave., New York, N. Y.

SEILER, ALVIN
Agent for Westinghouse Lamp Co., Greensburg, Pa.

SINCLAIR, H. A.
Secretary and Treasurer, The Tucker Elec. Construction Co., 114 W. 30th St., New York, N. Y.

THOMPSON, ROBT. J.
Manager, Welsbach Co., 863 Mission St., San Francisco, Cal.

TOMLINSON, L. C.
Electrical Engineer, 32 Greenleaf St., Malden, Mass.

WYNNE, V. C.
Consulting Engineer, 90 State St., Albany, N. Y.

Sustaining Membership.

The George Cutter Company of South Bend, Ind., and the New Haven Gas Light Company were elected sustaining members of the Society at a Council meeting held February 11.

Personals.

L. B. Marks and J. E. Woodwell, consulting engineers, 103 Park Avenue, New York City, announce that they will dissolve partnership on May 1, 1915. Mr. Woodwell will locate his offices at 8 West 40th Street, where he will continue the general practise of consulting engineer, and Mr. Marks will retain his offices at 103 Park Avenue and will specialize as heretofore in illuminating engineering.

Dr. Henry Phelps Gage and Prof. Simon Henry Gage are the authors of a book entitled "Optic Projection" published recently by the Comstock Publishing Co.

Mr. Douglass Burnett was elected chairman of the Commercial Section of the N. E. L. A. at a meeting held in Chicago, February 13.

Mr. Wilbur B. Foshay, formerly with the Northwestern Electric Co., is now president of the Washington Public Service Co. of Portland, Ore.

Mr. H. Foster Boggis is secretary and treasurer of the Boggis, Dietz Electric Co. in Milwaukee, Wis.

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Mr. E. B. Rowe, who in the last years has held successively the positions of resident engineer, assistant chief engineer and chief illuminating engineer of the Holophane Works, severed his connections with that organization March 1. Mr. Rowe is now secretary and engineer of the Enterprise Electric Construction & Fixture Co., 6509 Euclid Avenue, Cleveland, Ohio.

Back Numbers of the Transactions.

The Illuminating Engineering Society is desirous of obtaining copies of the following issues of the TRANSACTIONS:

1906 (Volume I):
 Nos. 1, 2, and 3.
1907 (Volume II):
 Nos. 1 and 2.
1914 (Volume IX):
 No. 7.

Members or others having copies of these numbers which they wish to dispose of should communicate with the general office of the Society, 29 West 39th Street, New York, N. Y.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 3, 1915

PART II

Miscellaneous Notes

Council Notes.

At a meeting of the Council held March 11, twenty-seven applicants were elected members of the society. Their names appear elsewhere in this issue of the TRANSACTIONS.

It was resolved that final action in dropping delinquents who owe for 1913 and 1914 dues be deferred until the June meeting.

Reports on section activities were received from the following vice-presidents: Mr. Ward Harrison for Pittsburgh; Prof. George A. Hoadley for Philadelphia; G. H. Stickney for New York; and F. A. Vaughn for Chicago.

It was voted that the Council accept the proposal of the Philadelphia Section to affiliate with the Engineers' Society of Philadelphia for the period of one year, with the understanding that the cost to the society will not exceed the sum of $350.00.

Progress reports were received from the following committees: Sustaining Membership, Popular Lectures, School Lighting, Remodeling the Lighting of the General Offices, Exhibition Booth (Gas), Exhibition Booth (Electric), Membership, Constitutional Revision, Lighting Legislation.

The following committee appointments were confirmed:

Mr. Douglass Burnett on the National Membership Committee.

Mr. Clarence L. Law, chairman of the Committee on Remodeling the Lighting of the General Offices.

Mr. E. S. Marlow, chairman of the 1915 Convention Committee.

The work of the 1914 Convention Committee being completed, it was voted that the committee be discharged with a hearty vote of thanks from the Council and the Illuminating Engineering Society for services rendered.

Those present at the meeting were: A. S. McAllister, president; H. Calvert, Ward Harrison, S. G. Hibben, George A. Hoadley, C. A. Littlefield, general secretary; L. B. Marks, treasurer; Preston S. Millar, Alten S. Miller, J. Arnold Norcross, G. H. Stickney. Upon invitation, Mr. A. Hertz, chairman of the Finance Committee.

A meeting of the Council was held April 8 in the general offices of the Society, 29 West 39th Street, New York, N. Y. Those present were: A. S. McAllister, president; E. M. Alger, C. O. Bond, H. Calvert, J. D. Israel, C. A. Littlefield, general secretary; L. B. Marks, treasurer; Preston S. Millar, Alten S. Miller, and J. Arnold Norcross.

Mr. Preston S. Millar, chairman of the Sustaining Membership Committee, announced that the sustaining membership dues of the Edison Lamp Works of the General Electric Co., Harrison, N. J., had been raised upon request of the member.

A written report on the Philadelphia Section activities by Prof. George A. Hoadley, vice-president, was read by Mr. H. Calvert.

A written report was received from the Committee on Membership. The report showed that since October 1, 1914, the additions to the membership totaled 117; the defections in the membership during the same period totaled 97, leaving a net gain of 20. The total individual membership as of April 8 was 1,492.

A written report was received from the chairman of the Committee on Remodeling the Lighting of the General Offices.

The committee was discharged with thanks.

A written report containing a list of proposed amendments to the Constitution was received from the Committee on Constitutional Revision. The report was also accompanied by a communication to the membership of the society which the committee recommended be sent out with the proposed amendments in advance of the election.

The proposed amendments having been received and considered favorably by the Council, it was resolved that the general secretary be instructed to send out the aforementioned communication and proposals previous to the forthcoming annual election.

The Committee on Glare from Reflecting Surfaces submitted two reports—the second and third of a series to be submitted by the committee—on the subject of "The Optical Properties of Diffusing Media." One gave a classification of diffusion, nomenclature and the physical theory of diffusion; the other dealt with instruments and methods for measuring diffusion and the theory of diffusion photometry.

It was resolved that the reports of this committee be put through the usual channel of publication, as they become available, and published in the TRANSACTIONS upon acceptance by the Committee on Papers.

Written reports were also received from the Committees on Editing and Publication, Reciprocal Relations with other Societies, and Section Development. Upon consideration of a recommendation contained in the report of the Committee on Editing and Publication—that all TRANSACTIONS cuts which are more than three years old be sold as junk—it was ordered that all line cuts which have been used in the TRANSACTIONS prior to the first of January of this year be destroyed, but all half-tones be retained.

The Committee on Lighting Legislation submitted a report stating that it had considered (1) a report containing material for formulating a code on factory lighting, which had been received from the Committee on Factory Lighting; (2) a report submitted by the Committee on School Lighting containing material upon which it is proposed to base a code on school lighting; and returned both reports to the respective committees with suggestions for revision.

The appointment of Mr. M. Luckiesh to the Committee on Lighting Legislation was confirmed.

It was announced that the 1915 Convention of the Society would be held at the New Willard Hotel, Washington, D. C., September 20-23 inclusive.

Communications were received from Mr. F. A. Vaughn, delegate of the I. E. S. to the Eleventh Annual Convention of the Illinois Gas Association; W. A. Ferguson of the Commonwealth Edison Company, in regard to holding Council meetings outside the city of New York; and E. C. Jones, president of the American Gas Institute, regarding the convention of his organization in San Francisco.

It was voted that Mr. C. O. Bond be asked to make recommendations to the president regarding the appointment of

two members of the I. E. S. to arrange for the presentation of two papers—to be credited to the I. E. S.—to be delivered at the San Francisco Convention of the American Gas Institute; and that the president be empowered to appoint such members.

It was suggested that a future meeting of the Council be held in Philadelphia or a city other than New York.

Section Activities.

Chicago Section.

Meetings.

March 25, 1915. Auditorium, Western Society of Engineers, Monadnock Block. Paper: "Color in Lighting," by M. Luckiesh. Attendance 63.

The tentative program of papers for the Chicago Section for the season 1914-1915 is as follows:

April—Lighting of Small Interiors: Homes; Small Offices; Show Windows.

May—Lighting of Large Interiors: Churches; Halls; Large Offices.

June—Lighting of Open Air Spaces: Streets; Building Exteriors; Signs.

New England Section.

Meetings.

March 26, 1915, Afternoon and Evening. Engineers' Club, 2 Commonwealth Ave., Boston, Mass. Papers presented in the afternoon: (1) "Daylight Glass," by Dr. H. P. Gage; (2) "Artificial Daylight," by R. B. Hussey; (3) "Semi-Indirect Lighting by Gas," by R. F. Pierce. Papers presented in the evening: (1) "Determining Factors in Artificial Illumination Problems Primarily as Related to Architecture and Decoration," by D. Crownfield; (2) "Safeguarding the Eyesight of School Children," by M. Luckiesh.

New York Section.

Meetings.

March 11, 1915. Engineering Societies Building. Paper: "A Practical Study of Car Lighting Problems," by Messrs. W. G. Gove and L. C. Porter. Mr. P. S. Bailey gave a demonstration of four different sizes of headlight lamps for interurban and suburban cars. Mr. G. H. Stickney demonstrated various systems of interior car lighting by means of a booth erected for this purpose. Mr. W. P. Horn exhibited a new car lighting reflector which has been suggested for railway cars. Attendance 80.

April 19, 1915. Auditorium of the Consolidated Gas Company's Building, 130 East 15th St. Joint meeting with the National Electric Light Association and the National Commercial Gas Association. Address by President Holton H. Scott, of the N. E. L. A. Papers: (1) "The Value of the Illuminating Engineering Society to Commercial Men," by Mr. Norman Macbeth; (2) "Illuminating Engineering as Applied to the Business of the Gas Company," by Mr. R. F. Pierce.

May—To be announced later.

Philadelphia Section.

Meetings.

March 19, 1915. Joint meeting with Franklin Institute. Papers: (1) "Photo-sculpturing," by Prof. J. Hammond Smith, illustrated; (2) "On the Choice of a Group of Observers for Heterochromatic Measurements"; (3) "Additional Experiments on Colored Absorbing Solutions for Use in Heterochromatic Photometry"; and (4) "A Method of Correcting Abnormal Color Vision and Its Application to Flicker Photom-

etry," by Dr. Herbert E. Ives and Mr. E. F. Kingsbury. Attendance 50.

April 16, 1915. Drexel Institute, 32nd and Chestnut Sts. Papers: (1) "The Problems of Lighting Design," by Prof. Arthur J. Rowland; (2) "Safeguarding the Eyesight of School Children," by M. Luckiesh.

The tentative program of papers for the Philadelphia Section for the season 1915 is as follows:

May 21—"Store Lighting," by W. R. Moulton. This meeting will be held in Baltimore, Md. The place will be announced later.

PITTSBURGH SECTION.

Meetings.

March 9, 1915. Joint meeting with the local section of the American Institute of Electrical Engineers. Papers: (1) "The Manufacture of New Types of Mazda Lamps," by Mr. R. E. Myers; (2) "The Use of Lenses in Signal Work," by H. S. Hower. Interesting exhibits illustrated both papers.

New Members.

The following twenty-seven applicants were elected members of the society at a meeting of the Council held March 11, 1915:

ARENBERG, ALBERT L.
Sales Engineer, Central Electric Co., 320 So. Fifth St., Chicago, Ill.

BELL, W. B.
Public Service Electric Co., 188 Ellison St., Paterson, N. J.

BULL, JOHN H.
Supervising Engineer, Ballinger & Perrot, Marbridge Building, New York, N. Y.

COX, W. A.
Public Service Electric Co., Newark, N. J.

DUVALL, BENJAMIN A.
Sales Dept., The Consolidated Gas Electric Light & Power Co., 100 W. Lexington St., Baltimore, Md.

FRENCH, C. H.
Public Service Electric Co., 759 Broad St., Newark, N. J.

GORGE, S. V.
Electrical Contractor, 8411 Eighteenth Ave., Brooklyn, N. Y.

HARRISON, BENJAMIN
Electrical Contractor, 6511 Eighteenth Ave., Brooklyn, N. Y.

JONES, W. L.
Manager, Fixture Dept., Electric Construction & Machinery Co., Electric Bldg., Rock Island, Ill.

MAYHEW, ZENAS D.
District Clerk, Edison Electric Illuminating Co. of Brooklyn, 360 Pearl St., Brooklyn, N. Y.

OWEN, CHARLES D.
New Business Assistant to the Division Agent, Public Service Electric Co., 118 Main St., Hackensack, N. J.

POTTER, N.
Public Service Gas Co., 188 Ellison St., Paterson, N. J.

PERKINS, M.
Public Service Gas Co., 418 Federal St., Camden, N. J.

RAMSEY, HAROLD E.
Assistant Electrical Engineer, Lehigh Coal & Navigation Co., Electrical Dept., Lansford, Pa.

SCHWARTZ, FREDERICK
Store Manager, Shapiro & Aronson, 20 Warren St., New York, N. Y.

SCHWARTZ, H. M.
Propr. Robt. Findlay M'f'g. Co., 349 Adams St., Brooklyn, N. Y.

SHEARER, E. P.
Public Service Gas Co., 271 N. Broad St., Elizabeth, N. J.

SMITH, A. A.
Public Service Electric Co., Newark, N. J.

SMITH, G. E.
Public Service Electric Co., Newark, N. J.

STIEREN, EDWARD
Ophthalmologist, Westinghouse Bldg., Pittsburgh, Pa.

TANZER, E. DEAN
Assistant Professor Electrical Engineering, Lafayette College, Easton, Pa.

THOMPSON, R. B.
Sales Dept. (Lighting) Central Hudson Gas & Electric Co., 129 Broadway, Newburgh, N. Y.

TINGLEY, LOUISA PAINE
Physician (Ophthalmologist), 9 Massachusetts Ave., Boston, Mass.

VAN GIESON, C. J.
Public Service Electric Co., Newark, N. J.

WALKER, J. H.
Assistant Engineer, C. L. Reeder, 921 Equitable Bldg., Baltimore, Md.

XYLANDER, P.
Public Service Gas Co., 118 Main St., Hackensack, N. J.

YOUNG, R. R.
Public Service Electric Co., 759 Broad St., Newark, N. J.

The following twenty applicants were elected members of the society at a Council meeting held April 8:

ALLEN, CHILE C.
Superintendent, Geo. S. Johnston Co., 5 S. Wabash Ave., Chicago, Ill.

AMBLER, THOMAS M.
Manager, Commercial Department, Brooklyn Union Gas Co., 176 Remsen St., Brooklyn, N. Y.

BRAUNS, H. E.
District Sales Agent, Milwaukee Electric Railway & Light Co., 429 Mitchell St., Milwaukee, Wis.

PALMER, BRIGGS S.
Optometrist, John W. Sanborn Co., 149 Tremont St., Boston, Mass.

BRYANT, ALICE G. (M. D.)
502 Beacon St., Boston, Mass.

CALLENDER, D. E.
General Manager, Wisconsin Gas & Electric Co., 305 6th St., Racine, Wis.

ENGLISH, FRANK F., 2ND.
Illuminating Engineer, 51 E. 42nd St., New York, N. Y.

FLYNN, M. F.
District Sales Agent, Milwaukee Electric Railway & Light Co., Public Service Bldg., Milwaukee, Wis.

FOOTE, FRANK H.
Manager, Specialty Department, Pettingell-Andrews Co., 511 Atlantic Ave., Boston, Mass.

GRANT, ALBERT WESTON, JR.
Photometrical Dept., United Gas Improvement Co., Philadelphia, Pa.

HARRIS, ARTHUR C.
District Sales Agent, Milwaukee Electric Railway & Light Co., Racine, Wis.

JAMISON, CHAS. M.
Manager, Merchandise Sales Dept., Milwaukee Electric Railway & Light Co., Public Service Bldg., Milwaukee, Wis.

JOHNSON, N. E.
Vice-President, The Linden Co., 1216 Michigan Ave., Chicago, Ill.

KRUSE, O. J.
District Sales Agent, Milwaukee Electric Railway & Light Co., Public Service Bldg., Milwaukee, Wis.

MONGER, H. G.
Chief Clerk, Sales Dept., Milwaukee Electric Railway & Light Co., Public Service Bldg., Milwaukee, Wis.

MONTGOMERY, T. M.
Manager, Lamp Dept., Elliott-Lewis Electrical Co., Inc., 138-40 N. 10th St., Philadelphia, Pa.

PEVEAR, MUNROE RHODES
Architect and Colored Light Specialist, Pevear Color Specialty Co. and Foss & Pevear, Architects, 71 Brimmer St., Boston, Mass.

REUTELER, A. C.
Manager, Watertown Gas & Electric Co., 205 Main St., Watertown, Wis.

VAN DERZEE, G. W.
Assistant to Vice-President, Milwaukee Electric Railway & Light Co., Public Service Bldg., Milwaukee, Wis.

WALL, WILLIAM L.
Secretary and Treasurer, Wall & Ocles, Inc., 1716 Chestnut St., Philadelphia, Pa.

Sustaining Membership.

The American Gas & Electric Co. of New York, the Brooklyn Union Gas Co. and the Edison Illuminating Co. of Detroit were elected sustaining members of the society at a Council meeting held April 8.

The following companies were elected sustaining members of the society March 11:

Edison Lamp Works of General Electric Company, Harrison, N. J.

Schenectady Illuminating Company, Schenectady, N. Y.

New Books.

MODERN ILLUMINANTS AND ILLUMINATING ENGINEERING—by Leon Gaster and J. S. Dow; 458 pp., price $5.00, the Macmillan Co., New York. Chapters on: history and development of methods of illumination; gas lighting; electric lighting; oil, petrol-air gas and acetylene lighting; illumination and the eye; color and the eye; measurement of light and illumination; globes, shades and reflectors, and calculations of illumination; problems in interior illumination; outdoor lighting. Bibliography appended.

Personals.

Mr. Harvey B. Wheeler, formerly with the National X-Ray Reflector Co., Chicago, Ill., is now chief engineer of the Pettingell-Andrews Co., Boston, Mass.

Prof. Alexander Silverman, director of the department of chemistry of University of Pittsburgh has recently given before several chemical societies a lecture constituting a survey of the chemistry and technology of glass making. Numerous specimens of glass were exhibited at each lecture.

Obituary.

George Cutter, vice-president of the George Cutter Co., South Bend, Ind., died of heart failure on April 6, 1915, in Los Angeles, Cal. He was born near Boston in 1853. In 1889 he started in business for himself in Chicago in the manufacture of electrical appliances. In 1898 he organized the George Cutter Co., manufacturers of specialties for outdoor electric lighting.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 4, 1915

PART II

Miscellaneous Notes

Council Notes.

A meeting of the Council was held May 13 in the general offices of the society, 29 West 39th Street, New York, N. Y. Those present were: A. S. McAllister, president; C. O. Bond, H. Calvert, George A. Hoadley, C. A. Littlefield, general secretary; L. B. Marks, treasurer; Alten S. Miller, Preston S. Millar, W. Cullen Morris, J. Arnold Norcross, and Geo. H. Stickney; upon invitation, George S. Barrows, C. E. Clewell, A. Hertz, and F. K. Richtmyer.

Reports on section activities were received from the following vice-presidents: George A. Hoadley, Philadelphia; Ward Harrison, Pittsburgh; G. H. Stickney, New York; and F. A. Vaughn, Chicago.

Upon recommendation of the Finance Committee, vouchers No. 2088 to No. 2095 and No. 2097 to No. 2129 inclusive, aggregating $921.81, were authorized paid.

After the reading of a written report by the chairman of the Committee on Factory Lighting, it was resolved that it is the sense of the Council that (1) the Committee on Popular Lectures should with due speed complete its lectures in order to have them ready for service; (2) that when they are completed, they shall be presented for action by the necessary committees, and for approval by the Council; (3) that immediately upon approval of the Council they shall be deemed ready for service upon demand; and that (4) they shall be printed in the TRANSACTIONS after approval by the Council and the usual committees.

Mr. J. Arnold Norcross, representative of the I. E. S. on the International Gas Congress, asked that the society cooperate in advertising the congress, which is to be held in San Francisco next September. It was voted that a notice concerning the congress be published in the next issue of the TRANSACTIONS.

Mr. C. O. Bond recommended the appointment of Messrs. G. S. Barrows and G. E. Hulse to present at the San Francisco convention of the American Gas Institute two papers which shall be credited to the I. E. S.

An oral report was made by Prof. F. K. Richtmyer, chairman of the Committee on Education. One member of the committee is to present a paper before the coming convention of the Society for the Promotion of Engineering Education.

A written report was received from Mr. Wm. Hand Browne, Jr., delegate of the I. E. S. to the presidential inaugural ceremonies of the University of North Carolina. It was voted that the report be acknowledged and a vote of thanks of the Council be extended to Mr. Browne.

Informal reports were made by Mr. G. H. Stickney, chairman of the Committee on Papers, and Mr. Preston S. Millar, chairman of the Committee on Sustaining Membership.

Communications were received from Messrs. M. M. Marks, president of the Borough of Manhattan; S. G. Hibben, secretary of the Pittsburgh Section, and C. L. Law.

The following committee appointments were confirmed:

Committee on Factory Lighting: D. M. Petty.

Committee of Election Tellers: L. J. Lewinson, chairman; H. V. Allen, Edgar H. Bostock, W. A. D. Evans, and A. L. Powell.

Section Activities.

CHICAGO SECTION

Meetings

April 22, 1915. Auditorium, Western Society of Engineers, Monadnock Building. Paper: "Knowns and Unknowns in the Lighting of Small Interiors," by Mr. James R. Cravath. The paper appears elsewhere in this issue of the TRANSACTIONS. Attendance 51.

May 21, 1915. Auditorium, Western Society of Engineers, Monadnock Building. Paper: "Principles of Scientific Street Lighting," by Mr. A. J. Sweet.

The tentative program of papers for the June meeting of the Chicago Section is as follows:

June—"Lighting of Open Air Spaces: Streets, Building Exteriors, Signs."

NEW YORK SECTION

Meetings

May 13, 1915. Engineering Societies Building. Papers: (1) "Illuminating Engineering as a Branch of Technical Instruction," by C. E. Clewell; (2) "Sheet Glass—Its Manufacture and Use for Illuminating Purposes," by E. H. Bostock. Attendance 85.

June—To be announced later.

PHILADELPHIA SECTION

Meetings

April 24, 1915. Joint meeting with the American Electro-chemical Society at the University of Pennsylvania.

May 21, 1915. Baltimore. Papers: (1) "Store Lighting," by Mr. W. R. Moulton; (2) "A Proposal Relative to Definitions, Standards and Photometric Methods," by Dr. H. E. Ives.

PITTSBURGH SECTION

Meetings

May 7, 1915. The Hofbrau, Cleveland, Ohio. Papers: (1) "Gas Street Lighting Development," by Mr. F. R. Hutchinson; (2) "Street Lighting with the Modern Arc Lamp," by Mr. W. P. Hurley; (3) "Recent Developments in Incandescent Street Lighting," by Mr. Ward Harrison. Attendance 55.

New Members.

The following three applicants were elected members of the society at a meeting of the Council held May 13, 1915:

HUDSON, RALPH GORTON
Instructor of Electrical Engineering, Massachusetts Institute of Technology, Boston, Mass.

JELLIFFE, C. N.
Vice-president and Treasurer, American Light & Traction Co., 40 Wall St., New York, N. Y.

TURNER, HUNTER HEINER
Ophthalmologist, 517 Jenkins Arcade Bldg., Pittsburgh, Pa.

Personals.

Mr. J. C. Schmidtbauer has been elected president of the Milwaukee Electrical League.

Mr. C. W. Bender has been appointed general manager of the Nela Specialties Division, recently organized to handle specialties manufactured by the National Lamp Works of the General Electric Company. He will also continue his present work as manager of the commercial department.

Obituary.

Mr. George Maurice, manager of the heating and light department of the General Electric Company, Ltd., of London, England, and one of the direc-

tors of that company, was one of the passengers reported lost in the sinking of the steamship Lusitania on May 7, 1915. Mr. Maurice had been in this country for several weeks on one of his numerous business trips. He was widely known in the electrical industry, both in this country and abroad.

Joint Session A. I. E. E. and I. E. S.

The American Institute of Electrical Engineers and the I. E. S. will hold a joint session on Wednesday evening, June 30, 1915, at Deer Park, Md., in conjunction with the 32nd annual convention of the institute. Two papers are scheduled for this session: "Systems of Street Illumination," by Dr. C. P. Steinmetz, and "The Effective Illumination of Streets," by Mr. Preston S. Millar. Copies of the latter paper may be had free about June 15 upon application to the general office of the I. E. S., 29 West 39th Street, New York, N. Y.

Results of 1915 I. E. S. Election.

The Committee of Tellers met May 27, 1915, in the general office of the society, and counted the votes of the 1915 annual election. The results reported by the committee showed that the following officers of the society and its several sections were elected for various terms beginning October 1, 1915:

President, Dr. C. P. Steinmetz; general secretary, Alten S. Miller; treasurer, L. B. Marks; vice-presidents, Clarence L. Law and J. L. Minick; directors, W. A. Durgin, M. Luckiesh, and J. Arnold Norcross.

Chicago Section—Chairman, E. W. Lloyd; secretary, O. L. Johnson; managers, A. O. Dicker, H. M. Frantz, C. A. Luther, A. H. Meyer, and F. A. Rogers.

New England Section—Chairman, Louis Bell; secretary, S. C. Rogers; managers, J. W. Cowles, W. B. Lancaster, George P. Smith, Jr., H. F. Wallace, and R. C. Ware.

New York Section—Chairman, D. McFarlan Moore; secretary, Norman D. Macdonald; managers, Thomas M. Ambler, L. H. Graves, W. F. Little, E. R. Treverton, and Herbert S. Whiting.

Philadelphia Section—Chairman, G. S. Crampton; secretary, L. B. Eichengreen; managers, George S. Barrows, Douglass Burnett, C. E. Clewell, R. B. Ely, and C. E. Ferree.

Pittsburgh Section—Chairman, Lewis J. Kiefer; secretary, R. H. Skinner; managers, Henry Harris, H. S. Hower, Harold Kirschberg, H. H. Magdsick, and G. W. Roosa.

The proposals to amend the constitution of the society were also adopted by a vote of more than five to one. The principal amendments include provisions which create a grade of membership to be known as members. The requirements for admission to this grade, as at present set forth, are somewhat higher than those of the other grade of individual members known as associate members. The annual dues of members will be $10.00 and of associate members $5.00.

DR. CHARLES P. STEINMETZ

Dr. Charles P. Steinmetz, president-elect, was born April 9, 1865, at Breslau, Germany. He was educated at the gymnasium (high school) and then at the University of Breslau, where he studied mathematics and astronomy, then physics and chemistry, and finally for a short time medicine and national economy. Involved in the social demo-

cratic agitation against the government, he escaped to Switzerland in 1888, and there studied mechanical engineering at the Polytechnische Zurich.

In 1889 he immigrated to America, and found a position with the Osterheld & Eichemeyer Manufacturing Company, first as draftsman, then as electrical engineer and designer, and finally on research work in charge of the Eichemeyer laboratory.

With the absorption of the Eichemeyer interests by the General Electric Company, Dr. Steinmetz joined the latter, and was attached to Mr. H. F. Parshall's calculating department in Lynn, Mass. With the transfer of the company's headquarters to Schenectady in the spring of 1894, Dr. Steinmetz organized and took charge of the calculation and design of the company's apparatus, and of the research and development work.

For a number of years Dr. Steinmetz was professor of electrical engineering at Union University, and at the present time is professor of electro-physics at that university, at the same time retaining his connection with the General Electric Company as chief consulting engineer. About the year 1910 he entered into closer relation with this company by organizing a consulting engineering department under his charge.

Among the more important publications and articles of which he is the author are a series of papers on each of the following subjects: polydimentional involutory correspondence; magnetic circuit and the law of hysteresis; dielectric and electrostatic phenomena; "Design and Performance of Electrical Apparatus," as transformers, induction machines, synchronous machines, commutating machines, etc.; "High Frequency Oscillations and Surges in Electric Circuits"; "Radiation, Light and Illumination"; "Mechanical Thermodynamics and Steam Turbines." Most of his papers on electrical subjects are published in the *Transactions* of the American Institute of Electrical Engineers.

The following books have been published by Dr. Steinmetz: A popular work on "Astronomy and Meteorology," in the German language, 1st edition 1889; "Theory and Calculation of Alternating Current Phenomena," 1st edition 1897, 4th edition 1908; "Theoretical Elements of Electrical Engineering," 1st edition 1901, 3rd edition 1909; "General Lectures on Electrical Engineering," 1st edition 1908, 4th edition 1910; "Theory and Calculation of Transient Electric Phenomena and Oscillations," 1909; "Radiation, Light and Illumination," 1909; "Electrical Engineering Mathematics," 1st edition 1910, 2nd edition 1914; "Electric Discharges, Waves and Impulses," 1911.

In 1902 Dr. Steinmetz received the honorary A. M. degree from Harvard University, and in 1903 the honorary Ph. D. degree from Union University.

Dr. Steinmetz is president of the National Association of Corporation Schools; vice-president of International Association of Municipal Electricians; honorary president of International Electrical Congress; past president of the American Institute of Electrical Engineers; honorary member of the National Electric Light Association; fellow of the American Association for the Advancement of Science; member of the (British) Institution of Electrical Engineers; members of the American Mathematical Society, the Quaternion Society, the Society of Mechanical Engineers, Electrochemical Society, Illumi-

nating Engineering Society, Physical Society, and a number of other organizations.

ALTEN S. MILLER

Mr. Alten S. Miller, general secretary-elect, was born in Richmond, Va., in 1868 and graduated from Stevens Institute of Technology in 1888 with the degree of mechanical engineer.

After leaving college he went with the United Gas Improvement Company of Philadelphia, and the same year was sent by that company to Omaha to take charge of its gas works in that city. In 1892 he was sent to Chicago as western sales agent of the United Gas Improvement Company and spent two years in that position.

In 1894 Mr. Miller went to New York, as engineer of the East River Gas Company of Long Island City. This company was then running a tunnel under the East River and building a plant to make gas in Long Island City, which was to be sold in New York. This company was later consolidated with one of the New York companies, forming the New Amsterdam Gas Company, and Mr. Miller was made the engineer of the latter. While holding that position he was made constructing engineer of the Consolidated Gas Company of New York in 1900.

In 1902 he became manager of the Consolidated Gas Company of Baltimore, Md., and in 1905 was made vice-president and general manager of the Consolidated Gas, Electric Light and Power Company of that city, which furnished all the gas and substantially all the electricity to the city and vicinity. While in Baltimore he built a new electric generating plant to replace the non-condensing generating plants, and also a new gas plant to replace three other manufacturing stations that had become obsolete.

In 1909 he went to St. Louis as president of the Union Electric Light and Power Company of that city. Here much was accomplished in reducing operating expenses and in gaining for the company the confidence and good will of the public. Much time was also spent in valuing the property and in the other details of a rate case before the Public Service Commission.

In 1911 he joined Dr. Alexander C. Humphreys in the company of Humphreys & Miller, Inc., of New York, N. Y. Since then he has confined his work to consulting engineering. He has made a special study of valuations and rate cases in connection with public service properties.

Besides being a member of the Illuminating Engineering Society, Mr. Miller is a fellow of the American Institute of Electrical Engineers and a member of the National Electric Light Association, American Gas Institute, American Society of Mechanical Engineers, Natural Gas Association, and the Society of Gas Lighting.

Special Transfer to Grade of Member.

The Council at its meeting held June 10, 1915, approved a special form of application to be used by Associate Members in applying for transfer to the grade of Member. A copy of the form appears on a following page. Associate members desiring to apply for transfer may fill in this form and send it to the general offices of the Society, 29 West 39th Street, New York, N. Y.

Under the amendments to the Constitution which were adopted at the recent annual election, all members of the Society passed automatically into a

new grade of associate member, except all general officers of the Society and members of the general Board of Examiners.

The dues of members shall be $10.00, and the dues of associate members $5.00. All associate members transferred to the grade of member between June 10 and October 1, 1915 shall not be required to pay any additional dues or fees for the fiscal year ending September 30, 1915.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 5, 1915

PART II

Miscellaneous Notes

Council Notes.

A meeting of the Council was held June 10, 1915, in the general offices of the society, 29 West 39th Street, New York, N. Y. Those present were: A. S. McAllister, president; E. M. Alger, C. O. Bond, H. Calvert, L. B. Marks, treasurer; Alten S. Miller, and G. H. Stickney.

It was resolved that the names of all those members owing dues for periods prior to October 1, 1914, be dropped from the roll forthwith.

It was resolved that all members (foreign members excepted as noted below) owing for current dues be notified that their names will be dropped from our roll, in accordance with the provisions of the Constitution and By-laws, July 1 if their dues are not paid in the meantime.

It was further resolved that the names of delinquent members whose current dues are unpaid on July 1 be dropped as of that date. Foreign members shall be allowed an additional 60 days' time; their names to be dropped September 1 unless their dues are received by that date.

A report on New York Section activities was received from Mr. G. H. Stickney.

A report was received from the Committee of Tellers giving the results of the annual election which was held in May. (The results were published, in accordance with a Council order, in the No. 4 issue of the TRANSACTIONS.)

The Committee on Constitutional Revision submitted (1) a temporary transfer application blank to be used by associate members in applying for transfer to the grade of member up to January 1, 1916; (2) a new application form to be used by all applicants in applying for either the grade of associate member or member.

The Council directed that the former application be published in the No. 4 issue of the TRANSACTIONS and that a separate blank be sent to each member of the society at the time of sending one of the several 1915 convention announcements.

After making a few changes in the wording of the membership application form submitted by the committee, it was ordered that this form be printed as the one prescribed by the Council, in accordance with the constitutional requirements.

It was resolved that all associate members transferred to the grade of member before October 1, 1915, shall not be required to pay any additional dues for the fiscal year ending September 30, 1915.

A progress report was received from the Membership Committee.

In accordance with a recommendation of the committee, the Council authorized, subject to the approval of the Finance Committee, an appropriation of $50.00 for another edition of the pamphlet on the work and objects of the society.

In accordance with a recommendation of the Finance Committee payment of vouchers No. 2096, and No. 2130 to No. 2166 aggregating $1,109.58 was authorized. The Finance Committee submitted a report showing that the total receipts from all sources during the first eight months amounted to $10,367.28, while the total cash disbursements amounted to $9,620.97.

In a report on the program of papers for the forthcoming convention of the society in Washington, the Committee on Papers stated that it had an unusually large number of excellent papers under

consideration. The number of papers of a commercial character scheduled for this year's program will in all probability necessitate separate sessions for them on two of the four days of the convention.

The Committee on Lighting Legislation reported that it expected to submit during the summer a final proof of a code on factory lighting. Copies of the code are to be available for distribution at the convention.

A progress report was received from the Committee on Popular Lectures and accepted with thanks.

Section Activities.

Chicago Section

June 22, 1915. Auditorium, Western Society of Engineers, Monadnock Building. Prof. Edw. L. Nichols of Cornell University gave a most interesting historical talk on the subject of "Artificial Lighting in 1900 and 1915," which was a resumé of the progress made in illumination up to 1915. An interesting and lively discussion followed the presentation of the paper. Mr. W. A. Durgin then announced the incoming officers for the next year and adjourned the meeting. An enjoyable dinner was held previous to the meeting at the Grand Pacific Hotel.

New York Section

June 14, 1915. Brevoort Hotel, 5th Avenue and 8th Street, New York City. Short talks on "What the Other Fellow Knows about Lighting Requirements" were given by Messrs. Charles W. Leavitt, landscape architect; Robert I. Aitken, sculptor; Harry Rowe Shelly, musician; E. J. Simmons, mural painter, and Horace Moran, architect. Forty-eight members and guests were present.

Pittsburgh Section

The final meeting of the year, held June 11, 1915, included an inspection trip to several factories of the United States Glass Company and a dinner. The members and guests met at the offices of the glass company at 8.00 p. m. and an exceptionally interesting trip was made through departments where the pressing and blowing of glass was being carried on. At 10 o'clock a special car transferred the party to the Fort Pitt Hotel, Dutch room, and there followed a dinner with several unique features. Souvenir drinking tumblers, etched with the society monogram and an appropriate legend, were given to those present. Addresses were made by members of the retiring and incoming boards of managers.

Personals.

Mr. L. B. Eichengreen has resigned as secretary of the Philadelphia Section. Mr. R. B. Ely has been appointed to succeed Mr. Eichengreen.

Mr. E. W. Lloyd of the Chicago Edison Company has been elected president of the National Electric Light Association for the coming year.

Mr. Frederick Schwartz, for the past sixteen years with Shapiro & Aronson, and until recently their store manager, has resigned to become treasurer and member of the recently incorporated concern of Robert Findlay Manufacturing Co., designers and manufacturers of lighting fixtures. Mr. Schwartz will be in immediate charge of the New York City salesrooms.

Prof. D. W. Blakeslee has resigned his position as assistant professor of electrical engineering in the University of Arkansas and is now in the engineer-

ing department of the Carnegie Steel Company, Farrell, Pa.

Mr. S. E. Shaff, formerly connected with the University at Iowa City, is now with the Electric Machinery Company, Minneapolis, Minn.

Obituary.

Mr. James P. Maila, chief electrician for Armour & Company, Chicago, died on May 29, as the result of an operation for appendicitis. He had been with Armour & Company for 29 years and since 1894 had been chief electrician. He had charge of the electrical work in all of the company's plants. He was a member of the Jovian Order, of the Illuminating Engineering Society, and of the Electric Club of Chicago.

New Members.

The following seven applicants were elected members of the society at a meeting of the Council held June 10, 1915:

HOUGHTON, C. P.
Second Vice-president, Los Angeles Gas & Electric Corporation, 645 S. Hill, St., Los Angeles, Cal.

HUMPHRY, GEORGE WILLIAM
Illuminating Engineer, Armstrong, Whitworth, Ltd., 4 Cottenham St., Newcastle-on-Tyne, England.

JELLETT, STEWART A.
Consulting Engineer, 1718 Real Estate Trust Bldg., Philadelphia, Pa.

KIRK, JAMES J.
Illuminating Engineer, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

SWAYNE, H. B.
General Contract Agent, Penn Central Light & Power Co., 1414 Eleventh Ave., Altoona, Pa.

VAN WINKLE, FRANK D.
Treasurer, The Post Glover Electric Co., 314 W. Fourth St., Cincinnati, Ohio.

WILSON, FRANK S.
Electrical Engineer, 8 Irvington St., Boston, Mass.

Sustaining Members.

The Portland (Me.) Gas Light Company and the Providence (R. I.) Gas Company were elected sustaining members at a meeting of the Council held June 10, 1915.

Program of 1915 Convention.

Following is a draft of the preliminary program of the ninth annual convention of the Illuminating Engineering Society which is to be held at the New Willard Hotel, Washington, D. C., September 20-23 inclusive. The papers, which promise to be of an unusually high standard, are to be distributed over ten sessions. One of the sessions will be devoted especially to the subject of street lighting; commercial, general, and laboratory papers will each be given three sessions. Inspection trips, a reception, and a banquet are among the entertainment features.

PROGRAM.

SEPT. 20—(Morning).

Formal opening of convention.

Address of Welcome; President's address, etc.

Reports of Committees on Lighting Legislation, Nomenclature and Standards, and Progress.

SEPT. 20—(Afternoon).

General Session.

Tests and Experiments in Connection with the New Commonwealth Edi-

son Company Building, by Messrs. W. A. Durgin and J. B. Jackson.
Ship Lighting, by H. A. Hornor.
Illumination Efficiency as Obtained in an Experimental Room, by Ward Harrison.

SEPT. 20—(Evening).

Reception.

SEPT. 21—(Morning).

General Session.

Photometry with Portable Instruments, by W. F. Little.
New Test Plate for Illumination Photometers, by C. H. Sharp.
Incandescent Lamp Testing and Photometry, by G. W. Middlekauff.
Street Lighting, by F. A. Vaughn.

SEPT. 21—(Afternoon).

Entertainment, trips.

SEPT. 21—(Evening).

Street Lighting Session.

Gas Street Lighting. (Author not yet announced.)
Arc Lamps for Street Illumination, by H. E. Clifford.
New Types of Incandescent Lamps and Their Relation to the Street Lighting Problems, by W. H. Rolinson.
Ornamental Street Lighting, by T. I. Jones.

SEPT. 22—(Morning).

Commercial Session.

How to Attack a Lighting Problem, by W. R. Moulton.
How can a Combination Gas and Electric Company Render the Best Services to Customers? by Messrs. S. B. Burrows and N. H. Potter.
Small Incandescent Lamps and Special Illumination Problems, by R. P. Burrows.
Lighting of Office Buildings, by A. O. Dicker.

Laboratory Session.

Crova's Method of Colored Light Photometry Applied to Modern Incandescent Illuminants, by Messrs. H. E. Ives and E. F. Kingsbury.
Differences in Threshold and Acuity Variations, by P. W. Cobb.
Visual Efficiency, by Messrs. Richtmyer and Howes.
Yellow Screens, by M. Luckiesh.

SEPT. 22—(Afternoon).

Commercial Session.

The Flame Pilot Ignition of Incandescent Gas Lamps, by C. W. Jordan.
Practical Illumination as Exemplified by Some Recent Installations of Incandescent Gas Lamps, by R. F. Pierce.
Mercury Arc Lamps for Industrial Lighting, by W. A. D. Evans.
Relation between Proper Illumination and Accident Prevention, by R. E. Simpson.

Laboratory Session.

Retinal Sensibilities in Relation to Illuminating Engineering, by P. G. Nutting.
The Effect of Distribution of Light on Muscular Control, by H. M. Johnson.
Effect of Various Wave-lengths of Radiation on Eye Cataract, by W. E. Berge.

SEPT. 23—(Morning).

Commercial Session.

Artificial Illumination of Interiors, by David Crownfield.
Lighting of State, War and Navy Buildings, by W. E. Chapman.
Lighting of Gymnasiums and Armories with Incandescent Lamps, by Messrs. A. L. Powell and A. B. Oday.

Laboratory Session.

The Effect of Surrounding Gas on an Incandescent Filament, by C. F. Lorenz.

The Parabolic Mirror, by F. A. Benford, Jr.

A paper (subject to be announced later) by C. E. Ferree.

SEPT. 23—(Afternoon).

General Session.

Artificial Illumination in Practical Photography, by C. E. K. Mees.

Photographic and Visual Illumination Efficiencies, by L. A. Jones.

Production and Application of Ultra-Violet Light, by M. Von Recklinghausen.

A Flux Method of Obtaining Average Illumination, by Messrs. T. A. Benford and H. E. Mahan.

Information regarding the convention may be had upon application to the general office of the society, 29 West 39th Street, New York.

International Gas Congress.

The International Gas Congress will be held in San Francisco during the week of September 27 to October 3. Details regarding special trains for delegates, hotel accommodations, papers, etc., may be had upon application to Mr. George G. Ramsdell, 29 West 39th Street, New York, N. Y. The fee of the congress is $5.00, which entitles the member to a copy of the published proceedings.

Among the features of particular interest to gas men at the Panama-Pacific Exposition are the special installations of gas lighting, and the gas exhibit. There are several miles of high pressure gas lighting. The "Joy Zone" of the exposition is illuminated by gas lamps concealed in ornamental lanterns. In the Court of Abundance there are gas fountains with serpents hissing streams of lighted gas. The effect is both unique and charming. The gas exhibit in the Palace of Manufactures covers a floor space of 10,000 square feet and includes a variety of interesting displays having to do with the manufacture, distribution and use of gas.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 6, 1915

PART II

Miscellaneous Notes

Washington Convention Papers.

Below is a condensed outline of the papers and reports to be presented at the ninth annual convention of the Illuminating Engineering Society, to be held at the New Willard Hotel, Washington, D. C., September 20-23, 1915. The summarized statements indicate that the papers are replete with new and valuable information on practically every phase of lighting. Many of the papers cover extensive special investigations conducted by authorities of high standing. For the commercial man or the solicitor who is interested chiefly in selling more and better lighting service there are a number of especially interesting contributions. Advance copies of practically all the papers and reports will be available for distribution by September 18 at the general office of the society, 29 West 39th Street, New York, N. Y.

PAPERS AND REPORTS.

1—Report of Committee on Nomenclature and Standards.
An annual report containing new terminology, definitions, symbols, etc.

2—Report of the Committee on Lighting Legislation.
A comprehensive statement of the status on lighting legislation; includes a code on lighting which was drafted by the committee.

3—Report of the Committee on Research.
Includes results of an extended investigation of the various methods of heterochromatic photometry.

4—Report of the Committee on Progress.
Reviews the features of lighting progress during the last year. For the most part the report, which is rather a long one, is a summary of published matter; but it also contains much valuable information not heretofore on general record.

5—Lighting of Ships, by H. A. Hornor.
The requirements of ship and marine lighting are set forth; methods of wiring and details of fixtures are discussed.

6—Lighting of a Passenger Steamer, by H. F. Spaulding.
Sketches past and present practise in marine lighting. Lighting requirements of a passenger boat are discussed and compared with similar installations ashore. Describes the lighting system on the S. S. Noronic, a lake passenger boat, and includes illumination test data.

7—Life Testing of Incandescent Lamps at the Bureau of Standards, by G. W. Middlekauff, J. F. Skogland, and B. Mulligan.
Outlines the methods of tests and inspections followed by the United States Bureau of Standards, and includes a description of laboratory equipment.

8—Use of Portable Photometers, by W. F. Little.
Outlines desirable procedure in the conduct of photometric tests with portable apparatus. Discusses the planning of a survey, and precautions which should be taken; a method of testing candlepower, illumination intensity and brightness; maintenance of photometric apparatus; photometric errors and means of avoiding them.

9—Compensating Illuminating Test-Plates, by C. H. Sharp.
A discussion of the various errors inherent in illumination test-plates in use and a description of a new form of construction which has been devised to eliminate those errors.

10—Illumination Efficiencies as Determined in an Experimental Room, by Ward Harrison and Earl A. Anderson.
A report on a series of illumination tests performed in a portable room designed for the purpose. The room dimensions and the arrangement of the outlets were varied to approximate the diverse conditions encountered in practise. Wall, ceiling and floor combinations of white, black and intermediate colors were tested with units of three general types of light distribution.

11—Semi-direct Office Lighting of the Chicago Edison Building, by W. A. Durgin and J. B. Jackson.
Gives a description of a typical office and comparative tests on five lighting systems, showing the relative eye fatigue, glare, shadows, etc. Data are given on the illuminating effectiveness, appearance, dust factor, etc., for the complete installation.

12—Street Lighting with Gas Lamps, by Geo. S. Barrows.
A discussion of modern street lighting with gas.

13—Arc Lamps for Street Illumination, by H. E. Clifford.
Outlines recent developments and characteristics of arc lamps designed for street illumination.

14—New Types of Incandescent Lamps and Their Relation to Street Lighting Problems, by W. H. Rolinson.
A brief historical review and consideration of the fundamental requisites of street lighting; various systems are classified according to unit and location. The choice of illuminants, means of regulation and general equipment are also discussed. Special attention is given to the recent developments in electric incandescent lamps for street lighting.

15—Application of Principles of Scientific Street Lighting, by F. A. Vaughn.
A comprehensive statement of the requirements of street lighting based upon a special investigation conducted in Milwaukee, Wis.

16—How Can a Combination Gas and Electric Company Render the Best Service to the Customer? by A. B. Spaulding and H. N. Potter.
Deals with the question of proper service to the customer; the education of salesmen and the customer; the relation between the salesman and the customer; and the question whether the sale of gas and electric illumination should be handled on a competitive basis or by combination men.

17—The Selection of a Standard Unit for Lighting, by W. H. Moulton.
Discusses the problem of selecting a new style of standard fixture for commercial work. Features of various lighting units are outlined.

18—Small Incandescent Lamps and Special Illumination Problems, by R. P. Burrows.

Deals with improvements in the manufacture of small incandescent lamps for novelties and the industrial and medical fields. A number of the present applications of these lamps are mentioned.

19—Illumination and One Year's Accidents, by R. E. Simpson.

Gives results of a study of one year's industrial accident records, the purpose of which was to determine the effect of the lighting conditions on the causation of accidents. Typical accidents are mentioned to show how lighting conditions have been responsible for injuries to workmen.

20—The Application of Crova's Method of Colored Light Photometry to Modern Incandescent Illuminants, by H. E. Ives and R. F. Kingsbury.

Discussion of the advantages and requirements of Crova's method for overcoming color differences in heterochromatic photometry.

21—The Relative Photographic and Visual Efficiencies of Light Sources, by L. A. Jones, M. B. Hodgsen and Kenneth Russ.

Sets forth the relation between the visual and photographic efficiencies of various lighting sources. Methods for the determination of these relations are outlined. A large amount of data is included to show the relations between several sources and three types of photographic plates.

22—A Method for Studying the Behavior of the Eye Under Different Conditions of Illumination, by F. K. Richtmyer and H. L. Howes.

Describes a method of studying visual efficiency which gives indications of being well adapted to quantitative measurements of the manner in which different conditions of illumination affect the working eye. Several curves are included to show the resemblances and differences in the rates of reading various matter by several observers. Other curves show the effects produced by placing frosted and unfrosted lamps in the field of vision.

23—The Flame Pilot Ignition of Incandescent Gas Lamps, by C. W. Jordan.

Features, advantages, and the application of various methods and systems of pilot ignition are discussed.

24—Practical Illumination as Exemplified by Some Recent Installations of Incandescent Gas Lamps, by R. F. Pierce.

A report on the various recent installations of gas lamps.

25—Mercury-vapor Lamps for Industrial Lighting, by W. A. D. Evans.

Outlines the lighting requirements of various industries, special reference being made to the application of the mercury-vapor lamp.

26—The Retinal Sensibilities Related to Illuminating Engineering, by P. G. Nutting.

Points out the retinal sensibilities of importance in illuminating engineering, such as sensibility to brightness and brightness differences and to color and color differences. The inter-relations of these sensibilities are outlined and methods given for their quantitative determination. The best data on each sensibility, including

much that is new, are summarized in each case.

27—Vision and Brightness of Surroundings, by P. W. Cobb.

Outlines the results of an investigation of visual acuity and difference-threshold. Describes new apparatus and methods used.

28—A Flux Method of Obtaining Average Illumination.

Describes a method of obtaining the average illumination from a lighting installation on the basis of the total flux generated by the light sources. The lower hemisphere surrounding the lighting unit is divided in three 30° zones, and the lighting unit classified according to the percentage of flux delivered in these zones. Having determined the proper classification for any lighting unit by means of one or more of the graphic charts shown, one is enabled to calculate the flux incident on the floor area for each unit and by adding these together determine the flux over the entire floor space.

29—Artificial Illumination of Architectural Interiors, by David Crownfield.

Deals with the lighting requirements of large interiors of different architectural styles and classes.

30—Artificial Lighting of Typical Offices in the State, War, and Navy Department Building, by W. E. Chapman.

Gives a brief description of the lighting conditions in a typical office of this building, which was erected in 1886. The present lighting requirements, and a description of the latest remodelled installation employing tungsten lamps are given.

31—Lighting in Downtown Office Buildings, by A. O. Dicker and J. J. Kirk.

Contains a description of typical downtown office buildings in the city of Chicago, representative of periods thirty, twenty, fourteen and six years ago. The lighting in these buildings is contrasted with an installation in a recently completed building in the same district.

32—Present Practise in the Lighting of Armories and Gymnasiums with Tungsten Filament Lamps, by A. L. Powell and A. B. Oday.

Gives descriptions and tabular tabular data on the lighting requirements of numerous armories and gymnasiums.

33—Ultra-violet Light and the Eye, by W. R. Burge.

An investigation to determine which wave-lengths in the ultra-violet region of the spectrum are harmful to living tissue, and the mode of action of these wave-lengths in producing injury.

34—Production and Application of Ultra-violet Rays, by M. von Recklinghausen.

A brief description of the different sources of ultra-violet rays. Includes a short description of the salient features of the system of sterilization of water by ultra-violet rays, and several pictures of recent plants.

35—The Parabolic Mirror, by F. A. Benford.

Directs attention to the increasing importance of parabolic reflectors for the projection of light for military and naval service, transportation, flood lighting and spectacular illumination. For the most

part a mathematical treatment of the reflector used with point, spherical and disk sources. Probably the most complete treatment of the theory of the reflector that has thus far been presented.

36—Some Experiments on the Eye with Inverted Reflectors of Different Densities, by C. E. Ferree and G. Rand.

The fourth of a series of papers in which the effect of the various conditions of lighting on the eye is investigated. Gradation of surface brightness is made the chief variable. Semi-direct reflectors of six degrees of density are employed and a correlation is made between the illuminating effects obtained and the tendency to cause loss of visual efficiency and to produce ocular discomfort.

37—The Effect of Variation of Atmospheric Pressure on the Candlepower of Flames, by E. B. Rosa, E. C. Crittenden and A. H. Taylor.

A summary of an investigation conducted at the United States Bureau of Standards.

38—Yellow Light, by M. Luckiesh.

Knowns and unknowns and the various opinions regarding yellow light are briefly discussed with respect to visual acuity, glare, fatigue, penetrating power, and esthetic value. Outlines the procedure involved in altering the light from tungsten lamps to match a light from the kerosene flame or the old carbon incandescent lamp.

39—Artificial Illuminants for Use in Practical Photography, by C. E. K. Mees.

Illuminants differ in efficiency, quality, size of source, consistency and flicker. Tables are given showing a classification of illuminants according to these characteristics when they are to be used with each of three classes of sensitive photographic materials: those sensitized to the whole spectrum, those with their sensitiveness in the blue violet, and those sensitive only to the ultraviolet. Another table shows a classification of various available artificial light sources according to the photographic operations for which they are suitable.

Personals.

Prof. W. S. Franklin has resigned as professor of physics at the Lehigh University, Bethlehem, Pa., with which he had been associated since 1897. He is now planning an extensive lecture tour of American universities and engineering schools.

Alfred O. Dicker, who for the greater part of the last six years has been connected with the illuminating engineering division of the contract department of the Commonwealth Edison Company, Chicago, has organized with two associates the Electrical Sales Engineers, Inc., with offices at 19 South Fifth Avenue, Chicago.

Robert S. Orr, who is general manager of the Duquesne Light Company, Pittsburgh, Pa., was elected fourth vice-president of the National Electric Light Association at its convention at San Francisco in June.

Mr. Walter Neumuller, who for the past five years has been assistant secretary of the Association of Edison Illuminating Companies, has been appointed special representative of the New York Edison Company. He is also a director,

treasurer and assistant secretary of the Electrical Show Company, director and treasurer of the New York Electric Vehicle Association, and director and member of the executive committee of the Electrical Refrigerating Company.

Mr. Joseph D. Israel, district manager for the Philadelphia Electric Company, was elected recently to serve as chairman of next year's convention of the sales managers of Edison illuminating companies.

Dr. A. S. McAllister, president of the Illuminating Engineering Society, resigned the editorship of the *Electrical World,* August 1, 1915.

New Books.

STANDARD HANDBOOK FOR ELECTRICAL ENGINEERS, compiled by Frank F. Fowle and a staff of specialists; 1984 pp., $5.00; McGraw-Hill Book Company, Inc., 239 West 39th Street, New York, N. Y. Contains chapters on the following topics: illumination; units, conversion factors and tables; electric and magnetic circuits; measurements and measuring apparatus; properties of materials; magnets, induction coils, condensers and resistors; transformers and rectifiers; alternating-current generators and motors; direct-current generators and motors; converters and double-current generators; power plants; power transmission; distribution systems; interior wiring; industrial motor applications; electric railways; electric commercial vehicles; electric ship propulsion; electrochemistry; batteries; telephony, telegraphy and radiotelegraphy; miscellaneous applications of electricity; mechanical section; standardization rules of the American Institute of Electrical Engineers; general engineering economics and central station economics.

The chapter on Illumination deals with production of light, incandescent lamps, carbon filament, metallized carbon filament, tantalum, tungsten, gas-filled type; arc lamp characteristics, carbon-electrode, flame arc, metallic electrode, tube lamps, lighting accessories, reflectors, indirect and semi-indirect lighting; illumination calculations, flux, candle-power, intensity, brightness, efficiency; applied illumination, fundamentals of vision, characteristics of illumination, physiological and psychological effects, methods, design, costs; photometry, fundamentals, standards, apparatus, spectrophotometers, colorimeters, and testing.

Section Notes.

The programs of meetings and papers of the several sections of the society for the coming season will be announced in the next issue of the TRANSACTIONS.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 7, 1915

PART II

Miscellaneous Notes

Section Notes.

NEW YORK SECTION

Meetings

October 14, 1915. Engineering Societies Building. Papers: (1) "Illumination in the Navy," by Lieut. C. S. McDowell of the Brooklyn Navy Yard; (2) "Illumination in the Army," by Capt. Edward D. Ardery, Corps of Engineers, U. S. Army. Attendance 85.

The following tentative program for the rest of the year has been announced:

November—A joint meeting with the American Electro-chemical Society. Papers on luminous gases by Messrs. D. McFarlan Moore and Walter V. Cady.

December—A paper on stage lighting.

January—A paper on lighting transmission and optical instruments by Dr. F. L. G. Kollmorgen; and a paper on projector lamps.

February—Joint meeting with the American Society of Mechanical Engineers. Mr. C. E. Clewell will present a paper on the factory lighting code of the Illuminating Engineering Society.

March—A lecture on illuminating engineering by Dr. Charles P. Steinmetz.

April—Papers on gas subjects.

May—Papers on street lighting.

June—Fine arts meeting.

PHILADELPHIA SECTION

The following program of the Philadelphia Section has been announced:

October 15—"Opportunities in the Lighting Field," by Norman Macbeth, Editor, *Lighting Journal.*

November 8—Joint meeting with Philadelphia Section of American Institute of Electrical Engineers. "New Code of Lighting for Factories, Mills and Other Work Places," by Prof. C. E. Clewell, Department of Electrical Engineering, University of Pennsylvania.

November 19—"Coal Mine Illumination and Its Relation to Accident Prevention and Miners' Nystagmus," by R. E. Simpson, Engineer, The Travelers' Insurance Company.

December 17—Joint meeting with Engineers' Club. "Illuminating Engineering," by Charles P. Steinmetz, A. M., Ph. D., President, Illuminating Engineering Society; Chief Consulting Engineer, General Electric Company.

January 21—"Illumination Problems at the Panama-Pacific Exposition," by W. D'A. Ryan, Illuminating Engineer, General Electric Company.

February 18—"Tests of Street Illumination," by Preston S. Millar, Past-president, Illuminating Engineering Society; General Manager, Electrical Testing Laboratories.

March 13—Joint meeting with Philadelphia Section, American Institute of Electrical Engineers. "Engineering Training as a Business Asset," by Charles F. Scott, Sc. D., Past-president, American Institute of Electrical Engineers; Professor of Electrical Engineering, Sheffield Scientific School of Yale University.

March 17—"Lighting Legislation," by L. B. Marks, Past-president, Illuminating Engineering Society; Consulting Engineer.

April 21—"Type C Lamps in Street Lighting," by T. J. Pace, Commercial Engineer, Westinghouse Electric & Manufacturing Company.

May 19—"Educational Aspects of Illumination," by Prof. F. K. Richtmyer, Chairman, Committee on Education, Illuminating Engineering Society.

June 16—"Artificial Lighting for a Hundred Years," by William J. Serrill, Engineer of Distribution, United Gas Improvement Company.

Annual Convention.

The ninth annual convention of the Illuminating Engineering Society was held at the New Willard Hotel in Washington, D. C., September 20-23 inclusive. There were twelve sessions, three of which were devoted to technical or laboratory subjects, three to commercial papers, one to street lighting, and the remaining four to general topics. All sessions were well attended and brought out a large amount of lively discussion. Among the entertainment features were a reception by Washington members and guests at the New Willard Hotel on Monday evening, September 20; a reception at the White House by President Woodrow Wilson at noon Tuesday; a drill by the United States Cavalry at Fort Myer, Va.; automobile trips for the ladies; and the annual banquet. A "get together" luncheon and discussion of society affairs was held on Thursday. The total registration was 350, including members and their guests. Without question the convention was a success and a fitting climax for the year's activities of the society.

New Members.

The following five applicants were elected associate members at a Council Executive Committee meeting held August 5:

HOWE, RALPH SAWYER
Illuminating Engineer, Mitchell Vance Company, 24th Street and Broadway, New York, N. Y.

KOCHERSPERGER, JEROME
Assistant Sales Engineer and Draughtsman, Central Electric Company, 320 South Fifth Avenue, Chicago, Ill.

MYER, ALBERT
Optometrist, 244 Broadway, Albert Lea, Minn.

WALKER, EDMUND ERNEST
Sales Engineer, Light and Power Department, British Columbia Electric Railway Company, Ltd., Canal Street, Vancouver, B. C.

WILLEY, LLEWELLYN M.
District Manager, Diehly Manufacturing Company, 1017 West Jackson Boulevard, Chicago, Ill.

At a meeting of our Council Executive Committee held August 18, the following applicants were elected associate members:

BOLTON, FRANK C.
Professor of Electrical Engineering, Agricultural and Mechanical College of Texas, College Station, Tex.

CRESSMAN, RUSSELL B.
Sales Department, Gleason Tiebout Glass Company, 71 West 23rd Street, New York, N. Y.

TAYLOR, A. HADLAY
Assistant Physicist, Bureau of Standards, Washington, D. C.

The following fifteen applicants were elected associate members at a meeting of the Council Executive Committee held September 23:

ANDERSON, EARL A.
National Lamp Works, General Electric Company, Nela Park, Cleveland, Ohio.

BURROWS, ROBERT P.
Electrical Engineer, National Lamp Works of General Electric Company, Nela Park, Cleveland, Ohio.

CHAPMAN, F. W.
Director, Technological Department, Newberry College, Newberry, S. C.

COE, GILBERT A.
Lighting Service Department, Philadelphia Electric Company, 1000 Chestnut Street, Philadelphia, Pa.

DORTING, E. E.
Lighting Engineer, Interborough Rapid Transit Company, 600 West 59th Street, New York, N. Y.

FULLER, WILLIAM J.
Illuminating Expert, Consumers' Gas Company, 19 Toronto Street, Toronto, Canada.

HELLMANN, C. B.
Salesman, Luminous Unit Company, 2615 Washington Avenue, St. Louis, Mo.

HOWARD-SOLER, ANTONIO
L. K. Comstock & Company, 30 Church Street, New York, N. Y.

LITTLE, ARLINGTON P.
Assistant Physicist, Bureau of Standards, Pierce Mill Road, Washington, D. C.

LORD, ALBERT C.
Purchasing Agent, Northern Union Gas Company, 1815 Webster Avenue, New York, N. Y.

PALMER, H. C.
Engineer, Buffalo Gas Company, 186 Main Street, Buffalo, N. Y.

SCHLADT, G. J.
Laboratory Assistant in Photometry, Bureau of Standards, Washington, D. C.

SMITH, ESMOND M.
Beardslee Chandler & Manufacturing Company, 216 South Jefferson Street, Chicago, Ill.

SULLIVAN, A. H.
Manager and Electrical Engineer, Columbia Electric & Engineering Company, 144 North 14th Street, Lincoln, Neb.

WILHOITE, L. J.
Contract Agent, Chattanooga Railway & Light Company, 710 Market Street, Chattanooga, Tenn.

New Sustaining Members.

The following companies were elected sustaining members at a Council Executive Committee meeting held August 5, 1915:

UTAH GAS & COKE COMPANY
Salt Lake City, Utah.

ST. LOUIS BRASS MANUFACTURING COMPANY
St. Louis, Mo.

Transfers.

The following applicants have been transferred from the grade of associate member to the grade of member:

AUGUST 18, 1915.

ABBOTT, ARTHUR L.
Manager, Electric Construction Company, 174 East 6th Street, St. Paul, Minn.

AUTY, K. A.
Chief Illuminating Engineer, British Columbia Electric Railway Company, Ltd., 1193 Bender Street, West, Vancouver, B. C.

BLAKESLEE, DORAF WILMOT
Engineering Department, Carnegie Steel Company, Farrell, Pa.

BOND, CHARLES O.
Manager, Physical Laboratory, United Gas Improvement Company, 3101 Passyunk Avenue, Philadelphia, Pa.

CLEWELL, C. E.
Assistant Professor of Electrical Engineering, University of Pennsylvania, Philadelphia, Pa.

CROWNFIELD, DAVID
Chief Designer and Illuminating Engineer, Pettingell-Andrews Company, 160 Pearl Street, Boston, Mass.

DATES, HENRY B.
Professor of Electrical Engineering, Case School of Applied Science, Euclid Avenue, Cleveland, Ohio.

DURGIN, WM. A.
Testing Engineer, Commonwealth Edison Company, 28 North Market Street, Chicago, Ill.

EVANS, WILLIAM A. D.
Commercial Engineer, Cooper-Hewitt Electric Co., 730 Grand Street, Hoboken, N. J.

FOSTER, SPOTTSWOOD C.
Superintendent and Electrical Engineer, Rappahannock Electric Light & Power Company, Charles and Amelia Streets, Fredericksburg, Va.

FLOY, HENRY
Consulting Engineer, 165 Broadway, New York, N. Y.

GRONDAHL, LARS O.
Assistant Professor of Physics, Carnegie Institute of Technology, Pittsburgh, Pa.

GRADLE, HARRY S.
Ophthalmologist, 32 North State Street, Chicago, Ill.

JACKSON, J. B.
Engineer of Lighting Service, Commonwealth Edison Company, 72 West Adams Street, Chicago, Ill.

JOHNSON, OTIS L.
Illuminating Engineer, Benjamin Electric Manufacturing Company, 120 South Sangamon Street, Chicago, Ill.

KIRSCHBERG, HAROLD
Consulting Illuminating Engineer, 650 Century Building, Pittsburgh, Pa.

KELLOGG, RAYMOND CLINTON
Assistant to Superintendent of Street Department (District No. 2), Brooklyn Union Gas Company, 176 Remsen Street, Brooklyn, N. Y.

LACOMBE, CHARLES F.
Consulting Engineer, 30 Broad Street, New York, N. Y.

LANSINGH, VAN RENSSELAER
President, The By-Lo Stores Company, 54 West Lake Street, Chicago, Ill.

LLOYD, E. W.
General Contract Agent, Commonwealth Edison Company, 72 West Adams Street, Chicago, Ill.

LUCKIESH, M.
Physicist, Nela Research Laboratory, National Lamp Works of General Electric Company, Nela Park, Cleveland, Ohio.

MASSON, CHAS. M.
Illuminating Engineer, Southern California Edison Company, 120 East 4th Street, Los Angeles, Cal.

MOON, T. ELMER.
Consulting Engineer in Illumination, 1626 Real Estate Trust Building, Philadelphia, Pa.

MOULTON, WALTER R.
Illuminating Engineer, Consolidated Gas, Electric Light & Power Company, 325 North Charles Street, Baltimore, Md.

NICHOLS, GEORGE B.
Chief Engineer, Department of Architecture, New York State Capitol, Albany, N. Y.

NUTTING, P. G.
Optical Engineer, Head of Physics, Research Laboratory, Eastman Kodak Company, Rochester, N. Y.

OHMANS, JOHN L.
Electrician in Charge of Car Lighting, Chicago & Western Indiana Railroad Company, 448 West 51st Street, Chicago, Ill.

REEDER, CHARLES L.
Consulting Engineer, Park Avenue Building, Park Avenue and Saratoga Street, Baltimore, Md.

ROLPH, T. W.
Illuminating Engineer, Ivanhoe Metal Works of General Electric Company, East Cleveland, Ohio.

ROWE, E. B.
Illuminating Engineer and Secretary, Enterprise Electric Construction & Fixture Company, 6509 Euclid Avenue, Cleveland, Ohio.

SCHMIDT, ALBERT R.
A. R. Schmidt Electric Company, 262 East Water Street, Milwaukee, Wis.

SCHEIBLE, ALBERT
Patent Attorney and Research Engineer, 79 West Monroe Street, Chicago, Ill.

SHARP, CLAYTON H.
Technical Director, Electrical Testing Laboratories, Inc., 80th Street and East End Avenue, New York, N. Y.

SPENCER, W. H.
Engineer and Assistant Manager, I. P. Frink, 239 Tenth Avenue, New York, N. Y.

THOMAS, STEPHEN A.
Chief, Electrical Division, Building Bureau, Department of Education, 500 Park Avenue, New York, N. Y.

WYNNE, V. C.
Consulting Engineer, 90 State Street, Albany, N. Y.

SEPTEMBER 23, 1915.

ADAM, JOHN N.
New Business Department, Public Service Electric Company, 271 North Broad Street, Elizabeth, N. J.

ALLEN, HARRY V.
Department of Water Supply, City of New York, 2324 Municipal Building, New York, N. Y.

AUERBACHER, LOUIS J.
Representative, Beck Searchlights, 120 Liberty Street, New York, N. Y.

BARROWS, GEORGE S.
Engineering Department, United Gas Improvement Company, Broad and Arch Streets, Philadelphia, Pa.

BARTLETT, P. H.
The Philadelphia Electric Company, 1000 Chestnut Street, Philadelphia, Pa.

BENFORD, FRANK A., JR.
Illuminating Engineering Laboratory, General Electric Company, Dock Street, Schenectady, N. Y.

BERNHARD, FRANK H.
Associate Editor, *Electrical Review* and *Western Electrician*, 608 South Dearborn Street, Chicago, Ill.

BETTS, PHILANDER
Chief Engineer, Board of Public Utility Commissioners, 790 Broad Street, Newark, N. J.

BOLTON, FRANK C.
Professor of Electrical Engineering, Agricultural and Mechanical College of Texas, College Station, Tex.

BOWEN, DUDLEY A.
Westinghouse Electric & Manufacturing Company, 165 Broadway, New York, N. Y.

BRONIS, JAMES
Appraiser of Unlisted Securities and Expert Accountant for Marvyn Scudder and The Investors' Agency, Inc., 55 Wall Street, New York, N. Y.

BROOKS, HAROLD ARTHUR
Electrical Engineer, Potomac Electric Power Company, 231 14th Street, N. W., Washington, D. C.

BROOM, BENJ. A.
Consulting Mechanical Engineer, 500 United Bank Building, Sioux City, Ia.

BRYANT, J. M.
Professor of Electrical Engineering, University of Texas, Austin, Tex.

BURROWS, STEPHEN B.
General Lighting Representative, Public Service Electric Company, 759 Broad Street, Newark, N. J.

CLINE, W. B.
President and General Manager, Los Angeles Gas & Electric Corporation, 645 South Hill Street, Los Angeles, Cal.

CRAMPTON, GEORGE S.
Ophthalmologist, 1700 Walnut Street, Philadelphia, Pa.

CRAVATH, JAMES R.
Consulting Electrical and Illuminating Engineer, 140 South Dearborn Street, Chicago, Ill.

CROSBY, HALSEY E.
Chief Electrician, Columbia University, 116th Street and Amsterdam Avenue, New York, N. Y.

DICKERSON, A. F.
Illuminating Engineer, General Electric Company, Panama-Pacific International Exposition, Service Building, San Francisco, Cal.

DUNNING, HERBERT S.
Westinghouse Lamp Company, Bloomfield, N. J.

EDIE, WM. W.
Illuminating Engineer, West Penn Electric Company, West Main Street, Connellsville, Pa.

EDWARDS, EVAN J.
Associate Engineer, National Lamp Works of General Electric Company, Nela Park, Cleveland, Ohio.

FULLER, W. W.
Chief Engineer and Manager, Charleston-Isle of Palms Traction Company, Charleston Hotel Building, Charleston, S. C.

GAST, FRED W.
Mechanical - Electrical Engineer, United States Treasury Department, Washington, D. C.

GROSS, J. HARRY
Park Engineer, Board of Park Commissioners, Druid Hill Park, Baltimore, Md.

HARE, JOHN R.
United Gas Improvement Company, 134 West 13th Street, Philadelphia, Pa.

HARRIES, GEORGE HERBERT
H. M. Byllesby & Company, Union Pacific Building, Omaha, Neb.

HATZEL, JOHN C.
Hatzel & Buehler, 373 4th Avenue, New York, N. Y.

HEILMAN, DONALD B.
Mechanical and Electrical Engineer, and Inspector, Philadelphia & Reading Railway Company, Reading, Pa.

HENNINGER, JOHN G., JR.
Salesman and Illuminating Engineer, Fostoria Incandescent Lamp Division, General Electric Company, Fostoria, Ohio.

HERING, CARL
929 Chestnut Street, Philadelphia, Pa.

HERRICK, CHARLES HUBBARD
National Meter Company of New York, 159 Franklin Street, Boston, Mass.

HERZOG, JOHN S.
Newark Reflector Division, National Lamp Works of General Electric Company, Newark, Ohio.

HIBBEN, S. G.
Illuminating Engineer, Macbeth-Evans Glass Company, Pittsburgh, Pa.

HICKS, LESLIE R.
Engineering Department, C. H. Tenney & Company, 201 Devonshire Street, Boston, Mass.

HITZKER, ALBERT J.
Assistant Manager, Federal Miniature Lamp Division, General Electric Company, 501 South Jefferson Street, Chicago, Ill.

HOUGHTON, C. P.
Second Vice-President, Los Angeles Gas & Electric Corporation, 645 South Hill Street, Los Angeles, Cal.

HUMPHRY, GEORGE WILLIAM
Sir W. G. Armstrong-Whitworth, Ltd., 10 Sarah Street, Shielsfield, Newcastle-on-Tyne, England.

HYDE, E. N.
Illuminating Department, Northern Electric Company, Ltd., Post Office Drawer 2040, Montreal, Can.

HYDE, E. P.
Director, Nela Research Laboratory, National Lamp Works of General Electric Company, Nela Park, Cleveland, Ohio.

JACKSON, DUGALD C.
Professor of Electrical Engineering, Massachusetts Institute of Technology, 248 Boylston Street, Boston, Mass.

JOHNSON, LESTER GURNEY
Commercial Engineer, General Electric Company, Schenectady, N. Y.

JONES, LOYD A.
Eastman Kodak Company, Rochester, N. Y.

JORDAN, HORACE W.
39 Boylston Street, Boston, Mass.

KRUGER, JOHN L.
137 Grand Avenue, Brooklyn, N. Y.

LAW, CLARENCE L.
Manager, Bureau of Illuminating Engineering, New York Edison Company, 130 East 15th Street, New York, N. Y.

LE PAGE, CLIFFORD B.
Assistant Professor of Physics, Stevens Institute of Technology, Hoboken, N. J.

LUTHER, CHAS. A.
Illuminating Engineer, Peoples Gas Light & Coke Company, 122 North Michigan Boulevard, Chicago, Ill.

MAGDSICK, H. H.
Engineering Department, National Lamp Works of General Electric Company, Nela Park, Cleveland, Ohio.

MIDDLEKAUFF, GEORGE W.
Associate Physicist, Bureau of Standards, Washington, D. C.

MILLAR, PRESTON S.
Manager, Electrical Testing Laboratories, Inc., 80th Street and East End Avenue, New York, N. Y.

MORGAN, JOHN EYRE
Superintendent Gas Plant, Pawtucket Gas Company, 231 Main Street, Pawtucket, R. I.

MORGAN, L. G. D.
Supervising Engineer, National X-Ray Reflector Company, 217 Stephenson Building, Milwaukee, Wis.

MOTT, WILLIAM ROY
Chemical Engineer, Research Laboratory, National Carbon Company, Corner 117th and Madison Streets, Lakewood, Ohio.

MYER, ALBERT
Secretary, American Optical Association, 244-246 Broadway, Albert Lea, Minn.

NEUMULLER, WALTER
Special Representative, New York Edison Company, 130 East 15th Street, New York, N. Y.

NODELL, W. L.
Sub-branch Manager, Westinghouse Lamp Company, 121 East Baltimore Street, Baltimore, Md.

NORTON, GUY PAYNE
Sterling Bronze Company, 16 West 40th Street, New York, N. Y.

OWENS, THURSTON
42 Pine Street, New York, N. Y.

PATTERSON, ROBERT B.
Superintendent, Street Lighting Department, Potomac Electric Power Company, 231 14th Street, N. W., Washington, D. C.

POPE, A. A.
Assistant General Commercial Manager, New York Edison Company, 130 East 15th Street, New York, N. Y.

RADCLIFF, JOHN R., JR.
Sales Manager (Electric), Yonkers Electric Light & Power Company, 9 Manor House Square, Yonkers, N. Y.

RIDINGER, CHAS. W.
President, Iron City Engineering Company, 711 Grant Street, Pittsburgh, Pa.

RIEHA, EDWARD L.
Gas Engineer and Contractor, 213 Courtland Street, Baltimore, Md.

ROCHESTER, THOMAS W.
Bureau Contract Supervision, Board of Estimate and Apportionment, Municipal Building, New York, N. Y.

SAWIN, GEORGE A.
Illuminating Engineer, Public Service Electric Company, 759 Broad Street, Newark, N. J.

SCHUMACHER, JOHN HENRY
Treasurer and Manager, Schumacher, Gray Company, Ltd., 386 Donald Street, Winnipeg, Manitoba, Can.

SCOFIELD, THOMAS
Consolidated Gas Company, 130 East 15th Street, New York, N. Y.

SHAAD, GEORGE C.
Professor of Electrical Engineering, University of Kansas, Engineering Building, University of Kansas, Lawrence, Kan.

SHAW, CARROLL H.
Electrical Engineer, Sheboygan Railway & Electric Company, 1514 North 7th Street, Sheboygan, Wis.

SHEIBLEY, FRANK D.
Assistant Engineer, Consolidated Telegraph & Electrical Subway Company, 54 Lafayette Street, New York, N. Y.

SILVERMAN, ALEXANDER
University of Pittsburgh, Pittsburgh, Pa.

STEADMAN, F. M.
Photographer, Concord, N. H.

STARK, A. W.
Engineer's Assistant, Consolidated Gas Company of New York, 130 East 15th Street, New York, N. Y.

STEINHARTER, JOS J.
Vice-president, Lamp Company, The Metalyte Company, 366 West 15th Street, New York, N. Y.

STEVICK, C. H.
Superintendent of Works, New Amsterdam Gas Company, Ravenswood, Long Island City, N. Y.

STEWART, SAMUEL B.
General Contracting Agent, Philadelphia Company, 435 Sixth Avenue, Pittsburgh, Pa.

SWALLOW, JOSEPH G.
Superintendent, Installation and Inspection Department, United Electric Light & Power Company, 130 East 15th Street, New York, N. Y.

TOMLINSON, L. C.
Electrical and Sales Engineer, National Electric Utility Corporation, 355 West 36th Street, New York, N. Y.

TYLER, RANDOLPH E.
Manager, Philadelphia Office, Shelby Lamp Division National Lamp Works of General Electric Company, 1941 Market Street, Philadelphia, Pa.

WARE, RICHARD C.
Assistant to Second Vice-president, Boston Consolidated Gas Company, 24 West Street, Boston, Mass.

WHITING, H. S.
J. Livingston & Company, 70 East 45th Street, New York, N. Y.

WEAVER, W. D.
Charlottesville, Va.

WILLIAMS, ARTHUR
General Commercial Manager, New York Edison Company, 130 East 15th Street, New York, N. Y.

WILSON, FRANK S.
Electrical Enginer, 8 Irvington Street, Boston, Mass.

YOUNG, JAMES WATTS
Consulting Electrical Engineer, 58 Townsend Street, Roxbury, Mass.

OCTOBER 14, 1915.

BOYCE, ERNEST W.
Electrical Engineer, President New York Electric Lamp Company, Inc., 30 Park Row, New York, N. Y.

BOXELL, HAROLD V.
Consulting Engineer and Professor of Electrical Engineering, University of Oklahoma, 508 Chautauqua Avenue, Norman, Okla.

BULL, JOHN H.
Supervising Engineer, Ballinger & Perrot, Marbridge Building, 34th Street and Broadway, New York, N. Y.

CADY, FRANCIS E.
Assistant to Director, Nela Research Laboratory, Nela Park, Ohio.

CARPENTER, FRANK
Illumination and Special Work, Welsbach Gas Lamp Company, 392 Canal Street, New York, N. Y.

CLINCH, EDWARD S., JR.
Electrical Engineer, Cates & Shepard, 1516 Sansom Street, Philadelphia, Pa.

COWLES, JOSEPH W.
Superintendent of Installations, Edison Electric Illuminating Company of Boston, 39 Boylston Street, Boston, Mass.

DOANE, L. C.
Commercial Engineer, Holophane Works of General Electric Company, Cleveland, Ohio.

DODSON, HERBERT K.
Assistant Superintendent, New Business and Merchandise Department, Consolidated Gas, Electric Light & Power Company of Baltimore, 200 West Lexington Street, Baltimore, Md.

DOTY, PAUL
President and General Manager, St. Paul Gas Light Company, 159 East 6th Street, St. Paul, Minn.

DOWS, CHESTER L.
Electrical Engineer, National Lamp Works of General Electric Company, Nela Park, Cleveland, Ohio.

DUTTON, L. R.
Manager, Philadelphia Suburban Gas & Electric Company, Wyncote, Pa.

GANZ, ALBERT FREDERICK
Consulting Engineer and Professor of Electrical Engineering, Stevens Institute of Technology, Hoboken, N. J.

HANSCOM, W. W.
Consulting Engineer, 848 Clayton Street, San Francisco, Cal.

HESS, WILLIAM L.
Oculist, 400 California Building, Denver, Colo.

HOLDREGE, H. A.
General Manager, Omaha Electric Light & Power Company, Omaha, Neb.

HULSE, GEO. E.
Chief Engineer, Safety Car Heating & Lighting Company, 2 Rector Street, New York, N. Y.

Jackson, Dugald C.
Professor of Electrical Engineering, Massachusetts Institute of Technology, 248 Boylston Street, Boston, Mass.

Keech, George C.
District Sales Manager, Cooper-Hewitt Electric Company, 215 Fisher Building, Chicago, Ill.

Kellogg, Alfred S.
Consulting Engineer, 53 State Street, Boston, Mass.

Kennedy, Geo. M.
Electrical Engineer, Lehigh Coal & Navigation Company, 110 East Ridge Street, Lansford, Pa.

Kingsbury, E. F.
Research Assistant, United Gas Improvement Company, Physical Laboratory, 3101 Passyunk Avenue, Philadelphia, Pa.

Magalhaes, George W.
Assistant to the President, New York & Queens Electric Light & Power Company, 444 Jackson Avenue, Long Island City, N. Y.

Marsh, Loren W.
New England Manager, American Luxfer Prism Company, 49 Federal Street, Boston, Mass.

Mixer, Chas. A.
Engineer, Rumford Falls Light & Water Company, 49 Congress Street, Rumford, Me.

Morton, F. N.
Engineer, United Gas Improvement Company, Broad & Arch Streets, Philadelphia, Pa.

Nicolai, G. O.
Superintendent, Light & Power Department, Terre Haute I. & E. Traction Company, 820 Wabash Avenue, Terre Haute, Ind.

O'Leary, J. J.
President, Buffalo Electric Contracting Company, 20 Broadway, Buffalo, N. Y.

Peaslee, W. Dhu Aine
Consulting Engineer, also Lecturer in Electrical Engineering, Oregon Agricultural College, Corvallis, Ore.

Porter, Lawrence C.
Illuminating Engineer, Edison Lamp Works of General Electric Company, 417 Sussex Street, Harrison, N. J.

Clover, Geo. R.
District Manager, Cooper-Hewitt Electric Company, 427 Ford Building, Detroit, Mich.

Rose, S. L. E.
Illuminating Engineering Laboratory, General Electric Company, Schenectady, N. Y.

Ryan, Walter D'Arcy
Director of Illuminating Engineering Laboratories, General Electric Company, Schenectady, N. Y.

Simpson, Richard E.
Engineer, Travelers' Insurance Company, 700 Main Street, Hartford, Conn.

Tingley, Dr. Louisa Paine
Ophthalmologist, 9 Massachusetts Avenue, Boston, Mass.

Treverton, E. R.
Lighting Engineering Service Company and *Lighting Journal*, 241 West 37th Street, New York, N. Y.

Wohlauer, A. A.
Consulting Engineer, Allied Engineering Company, 546 Fifth Avenue, New York, N. Y.

Murphy, John
Electrical Engineer, Government of Canada, Department Railways and Canals, Ottawa, Can.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 8, 1915

PART II

Miscellaneous Notes

Council Notes.

A regular meeting of the Council was held in the general offices of the society, 29 West 39th Street, New York, October 14, 1915. Those present were: Charles P. Steinmetz, president; H. Calvert, Wm. A. Durgin, Clarence L. Law, M. Luckiesh, A. S. McAllister, L. B. Marks, treasurer; J. Arnold Norcross, and G. H. Stickney.

The minutes of the June 10 meeting were adopted as printed.

The Council Executive Committee presented the following report giving a summary of its activities on behalf of the Council during the summer months:

Since the last meeting of the Council in June, the Council Executive Committee has:

(1) Held three meetings, August 5, August 18 and September 23, 1915.

(2) Authorized the payment of vouchers Nos. 2136-2138, 2167-2256 inclusive aggregating $2,461.82.

(3) Elected 23 associate members and 2 sustaining members.

(4) Accepted the resignations of 34 associate members.

(5) Transferred 123 associate members to the grade of member.

The report was adopted.

Six applicants were elected associate members.

Twenty-one associate members were transferred to the grade of member.

Upon recommendation of the Finance Committee, payment of vouchers No. 2257 to No. 2278 inclusive aggregating $1,250.28 was authorized.

Reports were given by Mr. G. H. Stickney, former vice-president of the New York Section; Mr. H. Calvert for Geo. A. Hoadley, vice-president of the Philadelphia Section, and Mr. L. B. Marks, chairman of the Committee on Lighting Legislation.

The following committee appointments were confirmed:

Finance: H. Calvert, chairman; J. A. Norcross, P. S. Young.

Papers: G. H. Stickney, chairman; A. S. McAllister, W. F. Little, G. W. Roosa, L. B. Marks, and the chairmen of section Papers Committees.

Editing and Publication: C. H. Sharp, chairman; Norman Macbeth, M. G. Lloyd.

Membership: Douglass Burnett, chairman; A. L. Abbott, J. J. Burns, W. R. Collier, S. L. E. Rose, A. M. Wilson, R. E. Simpson, T. M. Ambler, J. C. McLaughlin, and the chairmen of the section Membership Committees.

Sustaining Membership: W. M. Skiff, chairman; S. G. Hibben, E. W. Lloyd, E. B. McLean, S. L. E. Rose, E. B. Rowe.

Popular Lectures: E. J. Edwards, chairman; A. J. Rowland, vice-chairman.

a—*Sub-committee on Residence Lighting:* E. J. Edwards, chairman.

b—*Sub-committee on Industrial Lighting:* W. A. D. Evans, chairman; R. ff. Pierce.

c—*Sub-committee on Elementary Lecture:* W. S. Franklin, chairman.

d—*Sub-committee on Store Lighting:* A. L. Powell, chairman.

e—*Sub-committee on Office Lighting:* C. E. Clewell, chairman.

Lighting Legislation: L. B. Marks, chairman; O. H. Basquin, C. E. Clewell, Oscar H. Fogg, Clarence L. Law, M. Luckiesh, F. J. Miller, G. H. Stickney, L. H. Tanzer, W. H. Tolman, C. O. Bond, and F. A. Vaughn.

Glare: P. G. Nutting, chairman; Nelson M. Black, J. R. Cravath, F. H. Gilpin, M. Luckiesh, F. K. Richtmyer, F. A. Vaughn.

Progress: F. E. Cady, chairman; Walter B. Lancaster, T. J. Litle, Jr., L. B. Marks, F. N. Morton, T. W. Rolph.

Section Development: General Secretary, chairman; section secretaries.

Council Executive Committee: Chas. P. Steinmetz, chairman; L. B. Marks, H. Calvert.

Reciprocal Relations: W. J. Serrill, chairman; F. Park Lewis, F. E. Wallis, chairmen of sections, G. H. Stickney, C. H. Sharp.

Advertising: M. C. Turpin, chairman; J. C. McQuiston, Joseph D. Israel.

Nomenclature and Standards: A. E. Kennelly, chairman; C. H. Sharp, secretary; Louis Bell, C. O. Bond, S. E. Doane, W. A. Dorey, E. P. Hyde, C. O. Mailloux, A. S. Miller, P. G. Nutting, E. B. Rosa, W. E. Saunders.

Research: E. B. Rosa, chairman; P. W. Cobb, G. W. Middlekauff, P. G. Nutting, F. K. Richtmyer, C. H. Sharp, E. C. Crittenden, C. E. Ferree, E. P. Hyde, E. F. Kingsbury, Preston S. Millar, W. E. Wickenden, H. E. Ives.

It was decided to hold a semi-annual convention early in February to celebrate the 10th anniversary of the organization of the society.

After a discussion of the proposal to arrange for a course of lectures, similar to those presented at the Johns Hopkins University in the fall of 1910, to be given in the fall of 1916 under the auspices of the society, it was moved and carried that President Steinmetz be authorized to make such preparations as he deems desirable for the lecture course.

Thereupon the following committee appointments were confirmed, subject to changes:

a—*Committee on Ways and Means:* Preston S. Millar, chairman.

b—*Committee on Lectures:* L. B. Marks, chairman.

The resignation of Mr. Alten S. Miller, general secretary, was accepted.

It was moved and carried that the assistant secretary write Mr. A. S. Miller that the Council hopes he will retain his seat as a director.

A regular meeting of the Council was held in the offices of the society, November 11, 1915. Those present were: Charles P. Steinmetz, president; E. M. Alger, H. Calvert, G. A. Hoadley, Clarence L. Law, A. S. McAllister, J. L. Minick, L. B. Marks, C. O. Bond. Upon invitation: C. E. Clewell, G. H. Stickney.

The minutes of the October meeting were read, but adoption was postponed until they shall have appeared in print.

Nine applicants were elected associate members of the society.

Four applicants were elected sustaining members.

Thirty-eight associate members were transferred to the grade of member.

Upon recommendation of the Finance Committee, vouchers No. 2279 to No. 2316 inclusive aggregating $1,833.62 were authorized paid subject to the approval of the general secretary.

A report recommending certain rules of procedure with regard to the publication of papers and discussions was received from the Committee on Editing and Publication. Thereupon the question of the use of trade, firm, individual and corporate names in the publications of the society was raised for discussion. It was voted that the Committee on Editing and Publication be asked to draft some definite policy on this matter to be submitted at an early date, with the aforementioned rules, for the approval of the Council. It was understood that the members of the Council would be asked individually to communicate their views on the question to the committee.

The following committee appointments were confirmed:

Reciprocal Relations: Dr. E. M. Alger, chairman.

School Lighting: M. Luckiesh, chairman.

Lighting Legislation: C. E. Stephens.

Semi-Annual Convention: Arthur Williams, chairman.

Board of Examiners: A. S. McAllister, chairman; W. Cullen Morris, Bassett Jones.

It was voted that chairmen of committees who serve on other committees be listed, on the latter committees, as co-operating members.

The resignation of Mr. A. S. Miller as a director was accepted with a vote of thanks from the Council for services rendered.

Mr. C. A. Littlefield was appointed general secretary to succeed Mr. Alten S. Miller, resigned.

Mr. Preston S. Millar was appointed a director to succeed Mr. Alten S. Miller, resigned.

Mr. J. L. Minick was appointed a delegate of the society to attend the exercises of the Carnegie Institute of Technology in celebration of the eightieth birthday of Mr. Carnegie and the tenth anniversary of the founding of the Institute, to be held in Pittsburgh, Pa., November 23, 24, 1915.

Reports on section activities were received from Vice-presidents G. A. Hoadley and C. L. Law.

The question of time and place for giving the lectures on illuminating engineering was discussed informally. Mr. Clewell said that he thought the University of Pennsylvania would invite the society to give the lectures at the U. of P.

It was suggested that a design for a new membership certificate be drawn up and submitted for the approval of the Council.

It was decided to make the official badges of the society in the following colors: blue background for members; maroon for associate members, and white for honorary members.

The question was raised whether it would be desirable to draft a specification or statement of some kind for photographs and lantern slides showing comparative illuminated views which are used to illustrate papers given before the society. It was pointed out that these pictures are often misleading because of the absence of information regarding the conditions under which they are made. It was voted to refer this question to the Committee on Research.

New Associate Members.

At the October 14th meeting of the Council, the following six applicants were elected to associate membership:

GRAFF, WESLEY M. (Ph. B., M. E.)
Consulting Engineer, Graves Engineering Co., Inc., 35 Pine St., New York, N. Y.

NEWLIN, E. M.
Agent, New York Edison Co., Irving Place and 15th St., New York, N. Y.

NEWTON, ARTHUR HAZLETT
Electrical Engineer, Bureau of Public Works, Manila, P. I.

O'SHEA, JAMES P.
General Sales Agent, Cooper-Hewitt Electric Co., 730 Grand St., Hoboken, N. J.

ROBNETT, EDWIN H.
Representative, Westinghouse Electric & Manufacturing Co., 121 East Baltimore St., Baltimore, Md.

SCHERESCHEWSKY, J. W.
Surgeon, U. S. Public Health Service, U. S. Marine Hospital, Pittsburgh, Pa.

At the meeting of the Council held November 11, the following nine applicants were elected associate members:

BRANDRETH, GUY S.
Lighting Service Department, Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

CARDER, FREDERICK
Vice-president and General Manager, Steuben Glass Works, Corning, N. Y.

HUGHES, DAVID M.
Photometric Testing, Electrical Testing Laboratories, 80th St. and East End Ave., New York, N. Y.

MARKLEY, RALPH E.
Lighting Service Department, Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

MURRAY, JOSEPH BRADLEY
Acting Treasurer, Edison Electric Illuminating Co. of Brooklyn, 360 Pearl St., Brooklyn, N. Y.

PEARSALL, GEORGE MARTIN
Assistant in Physics, Cornell University, 415 North Cayuga St., Ithaca, N. Y.

PINCKLEY, W. F. T.
Newcastle Electric Supply Co., Hood St., Newcastle-on-Tyne, England.

REIN, FREDERICK E.
Business Engineer and Public Accountant, Frederick Rein & Staff, 1201 Chestnut St., Philadelphia, Pa.

KOEHLER, WILLIAM F.
Philadelphia Electric Co., 226 South 11th St., Philadelphia, Pa.

Section Meetings.

CHICAGO SECTION

November 4, 1915, in the Commonwealth Edison Company Building. Paper, "Semi-indirect Office Lighting in the Edison Building of Chicago" by Messrs. W. A. Durgin and J. B. Jackson. Attendance 250.

The following program of papers and meetings has been announced:

December 9—School Lighting.

January 13—Exterior Lighting (Gas and Electric) of Buildings.

February 10—Practical Factory Lighting.

February 28—Joint meeting of Chicago sections of A. I. E. E. and I. E. S. Paper on street lighting.

March 23—Latest Developments in Incandescent Lamps.

April 20—Latest Developments in Gas Lamps.

May 18—Relation of Illumination to Interior Architectural Effects.

June 15—Modern Reflectors and Shades for Gas and Electric Lighting.

The names of the authors of these papers will be announced later.

NEW ENGLAND SECTION

The first meeting of the section this year is to be held in February, 1916. A definite announcement will be made later.

NEW YORK SECTION

November 15, 1915. Joint meeting with American Electrochemical Society in Engineering Societies Building. Papers: (1) "Unstable States in the Arc and Glow" by Walter G. Cady of Wesleyan University, Middletown, Conn. (2) "Gaseous Conductor Light" by D. McFarlan Moore, Harrison, N. J. (3) "Electric Arc in Complex Vapors at

Reduced Pressures" by W. A. Darrah, Mansfield, O.

The following meetings have been announced:

December 8, 1915—Papers: (1) Progress in Home Lighting by Gas" by Thomas Scofield; (2) "Commercial Aspects of Gas Lighting" by Charles Hodgson.

January 13, 1916—Papers: (1) "Light Transmission in Optical Instruments" by Dr. F. L. G. Kollmorgen; (2 "Projector Lamps" by Mr. Orange of the General Electric Company.

March 9, 1916—Joint meeting with American Society of Mechanical Engineers: Paper by Prof. C. E. Clewell of the University of Pennsylvania on "Application of the New Factory Code."

April 13, 1916—A lecture by Dr. Charles P. Steinmetz, president of the Illuminating Engineering Society, on "Illuminating Engineering."

May 11, 1916—Papers: "Street Lighting" by S. G. Rhodes; "Office Lighting" by Bassett Jones; "Stage Lighting" by David Belasco.

Philadelphia Section

November 19, 1915, Engineers' Club, 1317 Spruce Street. Paper: "Coal Mine Illumination; its Relation to Accident Prevention and Miners' Nystacmus" by R. E. Simpson. Attendance 33.

The program for the rest of the year is as follows:

December 17—Joint meeting with Engineers' Club. "Illuminating Engineering," by Charles P. Steinmetz, A. M., Ph. D., President, Illuminating Engineering Society; Chief Consulting Engineer, General Electric Company.

January 21—"Illumination Problems at the Panama-Pacific Exposition," by W. D'A. Ryan, Illuminating Engineer, General Electric Company.

February 18—"Tests of Street Illumination," by Preston S. Millar, Past-president, Illuminating Engineering Society; General Manager, Electrical Testing Laboratories.

March 13—Joint meeting with Philadelphia Section, American Institute of Electrical Engineers. "Engineering Training as a Business Assett," by Charles F. Scott, Sc. D., Past-president, American Institute of Electrical Engineers; Professor of Electrical Engineering, Sheffield Scientific School of Yale University.

March 17—"Lighting Legislation," by L. B. Marks, Past-president, Illuminating Engineering Society; Consulting Engineer.

April 21—"Type C Lamps in Street Lighting," by T. J. Pace, Commercial Engineer, Westinghouse Electric & Manufacturing Company.

May 19—"Educational Aspects of Illumination," by Prof. F. K. Richtmyer, Chairman, Committee on Education, Illuminating Engineering Society.

June 16—"Artificial Lighting for a Hundred Years," by William J. Serrill, Engineer of Distribution, United Gas Improvement Company.

Pittsburgh Section

November 19, 1915. Educational meeting in Science Building, Carnegie Institute of Technology. Papers: (1) "Can Light be Measured?" by G. W. Roosa; (2) "Instruments that are Used in Measuring the Quantity of Light" by H. H. Magdsick; (3) "Instruments that are Used in Measuring Quality of Light" by Dr. L. O. Grondahl.

Transfers.

The following twenty-one applicants were transferred from the grade of associate member to that of member at a meeting of the Council held October 14, 1915:

ARENBERG, ALBERT L.
Illuminating Engineer, Central Electric Co., 320 South 5th Ave., Chicago, Ill.

BRADY, EDWARD J.
Physical Laboratory, United Gas Improvement Co., 3101 Passyunk Ave., Philadelphia, Pa.

CLARK, EMERSON L.
Physicist, National Carbon Co., Cleveland, O.

EICHENGREEN, L. B.
Gas Engineer, Manufacturer and Distributor of Gas, 1401 Arch St., Philadelphia, Pa.

GARTLEY, WILLIAM H.
Vice-president, Equitable Illuminating Gas Light Co., 1401 Arch St., Philadelphia, Pa.

GILPIN, FRANCIS H.
Gas Engineer, United Gas Improvement Co., 3101 Passyunk Ave., Philadelphia, Pa.

IVES, HERBERT E.
Physicist, United Gas Improvement Co., 3101 Passyunk Ave., Philadelphia, Pa.

JORDAN, C. W.
Assistant, Physical Laboratory, United Gas Improvement Co., 3101 Passyunk Ave., Philadelphia, Pa.

KELLY, J. B.
Salesman, Illuminating Department, Frank H. Stewart Electric Co., 37 North 7th St., Philadelphia, Pa.

KIEFER, LEWIS J.
Building Superintendent, McCreery & Co., Sixth Ave. and Wood St., Pittsburgh, Pa.

LITTLE, WILLIAM F.
Engineer in Charge of Photometry, Electrical Testing Laboratories, 80th St. and East End Ave., New York, N. Y.

MACDONALD, NORMAN D.
Assistant to Manager, Electrical Testing Laboratories, 80th St. and East End Ave., New York, N. Y.

PALMER, H. C.
Engineer, Buffalo Gas Co., 186 Main St., Buffalo, N. Y.

PIERCE, ROBERT FF.
Manager, Illuminating Engineering Laboratory, Welsbach Co., Gloucester, N. J.

ROGERS, FRED. A.
Professor of Physics and Electrical Engineering, Lewis Institute, Chicago, Ill.

SERRILL, WILLIAM J.
Engineer of Distribution, United Gas Improvement Co., 1401 Arch St., Philadelphia, Pa.

SNYDER, SAMUEL
Illuminating Specialist, New Business Department, The United Gas Improvement Co., 134 North 13th St., Philadelphia, Pa.

SPENCER, PAUL
Electrical Engineer, United Gas Improvement Co., 1401 Arch St., Philadelphia, Pa.

MORTON, A. A.
Westinghouse Electric & Manufacturing Co., Union Bank Bldg., Pittsburgh, Pa.

DICKER, ALFRED OSMOND
Illuminating Engineer, Electrical Sales Engineers, Inc., 19 South Fifth Ave., Chicago, Ill.

RICE, HARRY C.
General Manager, G. I. Lamp Division, National Lamp Works of General Electric Co., 214 Electric Bldg., Cleveland, O.

The following thirty-eight associate members were transferred to the grade of member November 11, 1915:

BOYCE, ERNEST W.
Electrical Engineer, President New York Electric Lamp Co., Inc., 38 Park Row, New York, N. Y.

BOXELL, HAROLD V.
Consulting Engineer and Professor of Electrical Engineering, University of Oklahoma, 508 Chautauqua Ave., Norman, Okla.

BULL, JOHN H.
Supervising Engineer, Ballinger & Perrott, Marbridge Bldg., 34th St. and Broadway, New York, N. Y.

CADY, FRANCIS E.
Assistant to director, Nela Research Laboratory, Nela Park, O.

CARPENTER, FRANK
Illumination and special work, Welsbach Gas Lamp Co., 392 Canal St., New York, N. Y.

CLINCH, EDWARD S., JR.
Electrical Engineer, Gates & Shepard, 1516 Sansom St., Philadelphia, Pa.

COWLES, JOSEPH W.
Superintendent of Installations, Edison Electric Illuminating Co. of Boston, 29 Boylston St., Boston, Mass.

DOANE, L. C.
Commercial Engineer, Holophane Works of General Electric Co., Holophane Works, Cleveland, O.

DODSON, HERBERT K.
Assistant Superintendent, New Business and Merchandise Department, Consolidated Gas, Electric Light & Power Co. of Baltimore, 200 W. Lexington St., Baltimore, Md.

DOTY, PAUL
President and General Manager, St. Paul Gas Light Co., 159 East 6th St., St. Paul, Minn.

DOWS, CHESTER L.
Electrical Engineer, National Lamp Works of General Electric Co., Nela Park, Cleveland, O.

DUTTON, I. R.
Manager, Philadelphia Suburban Gas & Electric Co., Wyncote, Pa.

GANZ, ALBERT FREDERICK
Consulting Engineer and Professor of Electrical Engineering, Stevens Institute of Technology, Hoboken, N. J.

HANSCOM, W. W.
Consulting Engineer, 848 Clayton St., San Francisco, Cal.

HOLDREGE, H. A.
General Manager, Omaha Electric Light & Power Co., Omaha, Neb.

HULSE, GEO. E.
Chief Engineer, Safety Car Heating & Lighting Co., 2 Rector St., New York, N. Y.

JACKSON, DUGALD C.
Professor of Electrical Engineering, Massachusetts Institute of Technology, 248 Boylston St., Boston, Mass.

KEECH, GEORGE C.
District Sales Manager, Cooper-Hewitt Electric Co., 215 Fisher Bldg., Chicago, Ill.

KELLOGG, ALFRED S.
Consulting Engineer, 53 State St., Boston, Mass.

KENNEDY, GEO. M.
Electrical Engineer, Lehigh Coal & Navigation Co., 110 E. Ridge St., Lansford, Pa.

KINGSBURY, E. F.
Research Assistant, United Gas Improvement Co., Physical Laboratory, 3101 Passyunk Ave., Philadelphia, Pa.

MAGALHAES, GEORGE W.
Assistant to the President, New York & Queens Electric Light & Power Co., 444 Jackson Ave., Long Island City, N. Y.

MARSH, LOREN W.
New England Manager, American Luxter Prism Co., 49 Federal St., Boston, Mass.

MIXER, CHAS. A.
Engineer, Rumford Falls Light & Water Co., 49 Congress St., Rumford, Me.

MORTON, F. N.
Engineer, United Gas Improvement Co., Broad and Arch Sts., Philadelphia, Pa.

NICOLAI, G. O.
Superintendent, Light and Power Dept., Terre Haute I. & E. Traction Co., 8 o Wabash Ave., Terre Haute, Ind.

O'LEARY, J. J.
President, Buffalo Electric Contracting Co., 20 Broadway, Buffalo, N. Y.

PEASLEE, W. DHU AINE
Consulting Engineer, also Lecturer in Electrical Engineering, Oregon Agricultural College, Corvallis, Ore.

PORTER, LAWRENCE C.
Illuminating Engineer, Edison Lamp Works of General Electric Co., 417 Sussex St., Harrison, N. J.

CLOVER, GEO. R.
District Manager, Cooper-Hewitt Electric Co., 427 Ford Bldg., Detroit, Mich.

ROSE, S. L. E.
Illuminating Engineering Laboratory, General Electric Co., Schenectady, N. Y.

RYAN, WALTER D'ARCY
Director of Illuminating Engineering Laboratories, General Electric Co., Schenectady, N. Y.

SIMPSON, RICHARD E.
Engineer, Travelers Insurance Co., 700 Main St., Hartford, Conn.

TINGLEY, DR. LOUISA PAINE
Ophthalmologist, 9 Massachusetts Ave., Boston, Mass.

TREVERTON, E. R.
Lighting Journal, 241 West 37th St., New York, N. Y.

WOHLAUER, A. A.
Consulting Engineer, Allied Engineering Co., 546 Fifth Ave., New York, N. Y.

MURPHY, JOHN
Electrical Engineer, Government of Canada, Department of Railways and Canals, Ottawa, Canada.

New Sustaining Members.

The following companies were elected sustaining members of the society at a meeting of the Council held November 11, 1915:

MALDEN AND MELROSE GAS LIGHT CO.
Clifford E. Paige, representative, 137 Pleasant St., Malden, Mass.

SUBURBAN GAS & ELECTRIC CO.
C. F. Chisholm, representative, 150 Beach St., Revere, Mass.

HAVERHILL ELECTRIC CO.
F. L. Ball, representative, 121 Merrimack St., Haverhill, Mass.

Personals.

Mr. Ray Palmer, formerly commissioner of electricity for the City of Chicago, assumed the office of vice-president and general manager of the New York and Queens Electric Light and Power Company, Long Island City, N. Y., November 1, 1915.

Mr. S. G. Hibben, who has been connected with the Macbeth-Evans Glass Company for a number of years, is now

with the National Lighting Products Company, Jenkins Arcade, Pittsburgh, Pa.

Mr. L. L. Hopkins, formerly with the Macbeth-Evans Glass Company, is now the Pittsburgh representative of the R. U. V. Company, Inc., 50 Broad Street, New York. His office is in the Magee Building, Pittsburgh, Pa.

Obituary.

Mr. E. S. Marlow, manager of the commercial department of the Potomac Electric Power Company, Washington, D. C., died October 25 after an illness of several months. Mr. Marlow was widely known in the central station field and had been active in the affairs of the Illuminating Engineering Society since its inception. He was chairman of the committee which had charge of the 1915 convention of the society in Washington, D. C.

Semi-Annual Convention.

A special semi-annual convention will be held in New York, February 10 and 11, 1916, to celebrate the tenth anniversary of the organization of the society. A detailed announcement will be issued later.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 9, 1915

PART II

Miscellaneous Notes

Council Notes.

Date: December 9, 1915.

Place: General Offices, 29 West 39th Street, New York, N. Y.

Present: Charles P. Steinmetz, president; E. M. Alger, C. O. Bond, H. Calvert, G. A. Hoadley, Clarence L. Law, C. A. Littlefield, L. B. Marks, Preston S. Millar, J. L. Minick, A. S. McAllister, J. Arnold Norcross, and S. C. Rogers, representing C. A. B. Halvorson.

The meeting was called to order at 2.55 p. m. by President Steinmetz.

The minutes of the October and November meetings were adopted as printed.

Six applicants were elected associate members.

One applicant was elected a member subject to the approval of the Board of Examiners.

Two companies were elected sustaining members.

Eleven associate members were transferred to the grade of member.

Sixty-three resignations were accepted.

It was voted to have the general office continue the occupancy of the present quarters in the Engineering Societies Building, New York.

Upon recommendation of the Finance Committee, payment of vouchers No. 2317 to No. 2349 inclusive aggregating $1,085.37 was authorized.

An estimate of the expenses and income for the present fiscal year was submitted by the Finance Committee, but no action was taken on it.

Reports on section activities were submitted by Vice-presidents J. L. Minick (Pittsburgh), G. A. Hoadley (Philadelphia), Clarence L. Law (New York). Mr. S. C. Rogers reported on the New England Section activities for Vice-president C. A. B. Halvorson.

The following committee appointments were confirmed:

Committee on Lectures: E. P. Hyde, chairman; Louis Bell, W. H. Gartley, L. B. Marks, C. H. Sharp, and W. D. Weaver.

Membership Committee: W. A. Durgin, chairman.

School Lighting Committee: F. Park Lewis, F. K. Richtmyer, L. O. Grondahl, N. M. Black, H. H. Magdsick, R. B. Ely.

Executive Committee: Preston S. Millar.

Semi-annual Convention Committee: Walter R. Addicks, William H. Bradley, N. F. Brady, A. W. Burchard, Nicholas Murray Butler, J. J. Carty, Charles A. Coffin, Geo. B. Cortelyou, Wilbur C. Fisk, Lewis B. Gawtry, Frank Hedley, W. Greeley Hoyt, A. C. Humphreys, M. R. Hutchison, J. W. Lieb, T. C. Martin, Wm. H. Meadowcroft, H. B. McLean, Joseph B. Murray, Thomas E. Murray, Walter Newmuller, L. A. Osborne, Geo. F. Parker, J. E. Phillips, Theodore P. Shonts, Frank W. Smith, B. W. Stilwell, C. G. M. Thomas, G. E. Tripp, W. F. Wells, Frederick Whitridge, Timothy S. Williams, William Williams, Clarence L. Law, secretary.

A letter was received from the provost of the University of Pennsylvania inviting the society to give its proposed course of lectures on illuminating engineering at the U. of P. This invitation was referred to the Committee on Ways and Means.

Section Meetings.

CHICAGO SECTION

December 9, 1915, in the Commonwealth Edison Company Building. Paper, "School Lighting" by M. Luckiesh. Preceding the meeting supper was served at the Grand Pacific Hotel.

The following program of papers and meetings have been announced:

January 13—Exterior Lighting (Gas and Electric) of Buildings.

February 10—Practical Factory Lighting.

February 28—Joint meeting of Chicago sections of A. I. E. E. and I. E. S. Paper on street lighting.

March 23—Latest Developments in Incandescent Lamps.

April 20—Latest Developments in Gas Lamps.

May 18—Relation of Illumination to Interior Architectural Effects.

June 15—Modern Reflectors and Shades for Gas and Electric Lighting.

The names of the authors of these papers will be announced later.

NEW ENGLAND SECTION

The first meeting of the section this year is to be held in February, 1916. A definite announcement will be made later.

NEW YORK SECTION

December 8, 1915, in Consolidated Gas Company's auditorium, 130 East 15th Street, New York, N. Y. Papers, "Outdoor Illumination of Store Fronts" by Charles Hodgson, and "Residence Lighting by Gas" by M. A. Combs. Preceding the meeting an informal and an a la carte dinner was held at Lüchow's Restaurant.

The following meetings and papers have been announced:

January 13—A paper will be presented by Mr. Kollmorgen of the Eastern Optical Company, entitled "Light Transmission in Optical Instruments" and also a paper by Mr. Orange of the General Electric Company, entitled "Projector Lamps."

By motion of the Board, the February meeting has been canceled in favor of the mid-winter convention.

March 14—Joint meeting with American Society of Mechanical Engineers. A paper will be presented by Prof. C. E. Clewell of the University of Pennsylvania entitled "Application of the New Factory Code Lighting." Talks will also be given by Mr. L. B. Marks and a member of the A. S. M. E.

April 13—A lecture by Dr. Charles P. Steinmetz on "Illuminating Engineering."

May 11—A paper will be presented by Mr. Bassett Jones, entitled "Office Lighting."

June—A paper will be presented by Mr. Wm. Dempsey of the New York Edison Company, entitled "Street Lighting with Mazda C Lamps."

It is proposed to have the June meeting an outdoor meeting to include a dinner and an inspection trip through the streets of New York.

PHILADELPHIA SECTION

December 17, 1915, in Engineers Club, joint meeting with Engineers Club and American Institute of Electrical Engineers. Dr. Charles P. Steinmetz addressed the members on the subject of "Illuminating Engineering."

The program for the rest of the year is as follows:

January 21—"Illumination Problems at the Panama-Pacific Exposition," by

W. D'A. Ryan, Illuminating Engineer, General Electric Company.

February 18—"Tests of Street Illumination," by Preston S. Millar, Past-president, Illuminating Engineering Society; General Manager, Electrical Testing Laboratories.

March 13—Joint meeting with Philadelphia Section, American Institute of Electrical Engineers. "Engineering Training as a Business Asset," by Charles F. Scott, Sc. D., Past-president, American Institute of Electrical Engineers; Professor of Electrical Engineering, Sheffield Scientific School of Yale University.

March 17—"Lighting Legislation," by L. B. Marks, Past-president, Illuminating Engineering Society; Consulting Engineer.

April 21—"Type C Lamps in Street Lighting," by T. J. Pace, Commercial Engineer, Westinghouse Electric & Manufacturing Company.

May 19—"Educational Aspects of Illumination," by Prof. F. K. Richtmyer, Chairman, Committee on Education, Illuminating Engineering Society.

June 16—"Artificial Lighting for a Hundred Years," by William J. Serrill, Engineer of Distribution, United Gas Improvement Company.

PITTSBURGH SECTION

December 17, 1915, at Engineers' Society of Western Pennsylvania. Paper, "Design and Manufacture of Diffusing Glass Reflectors" by S. G. Hibben. An a la carte dinner was held at the Fort Pitt Hotel.

New Associate Members.

The following six applicants were elected associate members at a Council meeting held December 9, 1915:

BABSON, A. C.
Watertown Manager, Wisconsin Gas & Electric Co., 205 Main St., Watertown, Wis.

HOUSEKEEPER, WILLIAM G.
Electrical Engineer, Western Electric Co., 463 West St., New York, N. Y.

MARLOW, S. L.
Salesman, Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

OSHIMA, HIRO-YOSHI
Osaka Electric Lamp Co., 70 Daini, Sagisu-cho, Osaka, Japan.

RUTH, ROBERT H.
Benjamin Electric Manufacturing Co., Pittsburgh, Pa.

SPILLAN, JAMES J.
Laboratory assistant, Philadelphia Electric Co., 226 S. 11th St., Philadelphia, Pa.

New Sustaining Members.

The following companies were elected sustaining members of the society at a Council meeting held December 9, 1915:

AMERICAN OPTICAL CO.
Southbridge, Mass. Official Representative, Howard T. Reeve.

MALDEN ELECTRIC CO.
Malden, Mass. Official Representative, Cyrus Barnes.

Transfers.

Eleven associate members were transferred to the grade of member at a meeting of the Council held December 9, 1915:

BIERMAN, CHAS. F.
Telephone Engineer, Wisconsin Telephone Co., 183 Fifth Ave., Milwaukee, Wis.

Bryant, Alice G.
Physician, 502 Beacon St., Boston, Mass.

Caldwell, F. C.
Professor of Electrical Engineering, Ohio State University, Columbus, O.

Goldmark, C. J.
Consulting Engineer, 103 Park Ave., New York, N. Y.

Macbeth, Norman
241 W. 37th St., New York, N. Y.

Maxwell, James T.
General Agent, Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

McGuire, Frederick J.
Chief Inspector investigating illuminating and power economies, Dept. of Water Supply, Gas and Electricity, Municipal Bldg., New York, N. Y.

Murray, Joseph Bradley
Acting Treasurer, Edison Electric Illuminating Co. of Brooklyn, 360 Pearl St., Brooklyn, N. Y.

Rogers, S. C.
General Electric Co., West Lynn, Mass.

Stafford, Raymond W.
New York Edison Co., 124 E. 15th St., New York, N. Y.

Steinmetz, Charles P.
Consulting Engineer, General Electric Co., Schenectady, N. Y.

New Books.

Color and Its Application, by M. Luckiesh, Physicist, Nela Research Laboratory, National Lamp Works of General Electric Company, Cleveland, Ohio; 360 pp., price $3.00; published by D. Van Nostrand Company, 25 Park Place, New York, N. Y. Contents: light; the production of color; color mixture; color terminology; the analysis of color; color and vision; the effect of environment on color; theories of color vision; color photometry; color photography; color in lighting; color effects for the stage and displays; color phenomena in painting; color matching; the art of mobile color; color media.